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Embodied carbon footprint calculation based on building information model

The School of Chemical Technology

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ABSTRACT OF THE
MASTER'S THESIS

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The goal of this study was to find out, how the building information model (BIM) data is utilized in embodied carbon footprint calculation.
Information about calculation softwares and the current situation of the calculations were gathered through literature review and semistructured interviews. Framing of this study presumed compatibility with industry foundation classes (IFC).
The embodied carbon footprint calculation softwares are usually specialist level lifecycle assessment calculation tools for heavy calculation in the end of building project.
The result of the study was that no functional information workflow from design software to carbon footprint calculations could be found. The building design softwares could export information in table format for the calculation, but which information is selected for the tables depends on the person doing the calculations. Connecting databases into building design software would make calculations faster and reduce the variation. Direct information exchange would also make them less prone to errors and slow manual intervention.
The biggest advantage of the carbon footprint calculation could be received in the early phase of the project when it could guide the design. Therefore it would be important to develop calculation tools that could be directly or via IFC integrated with the design softwares.
The standards to define the carbon footprint of buildings are clear, but they allow some deviation for used methods and the results are usually not directly comparable.
The databases of building materials should include both more area specific and design phase sensitive information in order to receive accurate calculation results in various occasions.
Official rules could speed up the change of the conventions in the building sector.

Keywords: embodied carbon, carbon footprint, BIM, IFC

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Tutkimuksen päämäärä oli selvittää materiaalien hiilijalanjäljen laskentaa rakennuksen tietomallin pohjalta.
Tietoja laskentaohjelmista ja laskennan tämänhetkisestä tilanteesta selvitettiin kirjallisuuskatsauksella sekä puolistrukturoitujen haastattelujen avulla. Tutkimus rajattiin koskemaan vain IFC-standardin (industry foundation classes) mukaista tiedonsiirtoa tukevia laskentaohjelmia.
Rakenteisiin sitoutuneen hiilijalanjäljen laskentaohjelmat ovat raskaita asiantuntijatyökaluja, joita käytetään yleensä vasta rakennussuunnitelman valmistuttua.
Yhtään toimivaa standardin mukaista tiedonsiirtolinkkiä suunnittelu- ja laskentaohjelmien välillä ei löytynyt. Rakennussuunnitteluohjelmista pystyy siirtämään tietoa taulukkomuodossa laskentaohjelmiin. Taulukon tietojen valikointiin liittyy kuitenkin laskijakohtaisia eroja. Materiaalitietokantojen yhdistäminen suunnitteluohjelmiin nopeuttaisi laskelmia ja vähentäisi hajontaa. Suora tiedonsiirto myös vähentäisi käsin tehtävää työtä, joka on hidasta ja virhealtista.
Hiilijalanjälkilaskennasta olisi eniten hyötyä projektin alkuvaiheessa, jolloin se voisi ohjata suunnittelua. Siksi olisi tärkeää kehittää laskentaohjelmia, jotka voisi integroida suoraan rakennussuunnitteluohjelmiin.
Hiilijalanjälkilaskentaa määrittelevät standardit ovat selkeitä, mutta ne jättävät laskentamenetelmille liikkumatilaa. Tämän takia laskelmien tulokset eivät ole läheskään aina suoraan verrattavissa toisiinsa.
Rakennusmateriaalien tietokantojen pitäisi sisältää entistä enemmän aluekohtaisia ja eri suunnitteluvaiheisiin optimoituja arvoja, jotta laskentatulokset olisivat käyttökelpoisia eri tilanteissa.
Viralliset vaatimukset voisivat nopeuttaa toimintatapojen muutosta rakennusalalla.

Avainsanat: sitoutunut hiili, hiilijalanjälki, BIM, IFC

Preface

This master's thesis was originally part of the €CO2 project in which I participated on behalf of M.A.D. When I started this study I had already worked with ArchiCAD, a BIM software, for several years.

It was interested in participating in a great European project which also strove for more effective exploitation of BIM. This study has required a lot of work and many sleepless nights. Now I understand the significance of tenacious work, into which I by myself could occasionally submit as well.

A great many people have had a hand in this project over the years. I want to thank all members of the €CO2 project including my advisors and my employer M.A.D. for sharing the latest information. I also want to thank the interviewees for providing their expertise for my use, my professors and teachers from Aalto University for their support and patience during my studies, my colleagues for support, my very dear friends who listened and helped me over both technical and mental problems, and my family who was always there for me. Without you the assignment would have been impossible.

Otaniemi, April 2015

Jenni A. M. Kemppainen

Contents

Abbreviations

AFNOR	Association Français de Normalisation
BIM	Building information model(ing)
buildingSMART	buildingSMART International,
	American–European coalition of AEC companies, former IAI.
CAD	Computer aided design
CO_2	carbon dioxide
COBIE	Construction-Operations Building Information Exchange
€CO2	Wood in Carbon Efficient Construction – EU project
EERE	Office of Energy Efficiency and Renewable Energy
EN	European standard
EPD	Environmental product declaration
FIGBC	Green building council in Finland
GWP	Global Warming Potential
gbXML	Green Building XML schema
GHG	Green house gas
ICT	Information and communications technology
IDM	Information Delivery Manual
IES	Integrated Environmental Solutions (company)
IFC	Industry foundation class
IFD	International Framework for Dictionaries
ISO	International Organization for Standardization
LCA	Life cycle assessment
LCI	Life cycle inventory study
	OR Life cycle inventory analysis
LCIA	Life cycle impact assessment
MEP	Ductwork, pipework and cabling
MVD	Model view definition
RTS	Rakennustietosäätiö, Building Information Group in Finland
UNEP	United Nations Environment Programme
VTT	VTT Technical Research Centre of Finland Ltd.
	(Fin. *Teknologian tutkimuskeskus VTT Oy*)

1 Introduction

This work started as a part of the EU project *€CO2 – Wood in Carbon Efficient Construction*, which focuses on carbon efficient wood constructions. The scope of the €CO2 project was to understand carbon efficiency in the full life-cycle of a building, especially wooden structures in mind. In addition, the goal was to find solutions for calculating and optimizing the carbon footprint of the building. The project was funded through WoodWisdom-Net and it had 20 partners including universities in five European countries. One of the partners was Aalto University, to which this work is written and another partner was Micro Aided Design Oy, the ArchiCAD distributor in Finland, also the employer of the writer.

More attention is paid to ecological thinking all the time. Environmental requirements evolve continuously, and in order to fulfill them effective working tools would be essential. Still, based on regarding this study there are only few applications where the required ecological calculations can be carried out smoothly and without remodeling the entire building. This is the situation even when the question is about official requirements, not even mentioning additional calculation possibilities, like embodied carbon footprint calculation handled in this study. In best case the initial calculations, environmental or cost estimations, are made in the very beginning of the building design process so that they can be used to steer the design process.

Using the study surprisingly much information about the carbon footprint calculation compared to how poorly the calculation process has been connected into design softwares in practice. This means, that there is information, but no functioning real life solutions that would not require manual interference. There are hundreds of building design and calculation softwares available, but they hardly communicate with each other. The situation reminds of the time when values had to be fed manually from screen to paper and later from paper back to screen. While building information modeling, or shortly just BIM, slowly gains ground, there are several areas where exploiting the technology is not yet even close to what it could be.

The writer has worked with architectural design software and therefore the reality of the building design process and its deficiency what comes to the information flow is familiar.

Research subject and methods

The goal of this study is to report the current situation of carbon footprint calculation in the early stage of the building design. The core question is, how is building information model (BIM) utilized in carbon footprint calculation.

The data for this research is collected from literature, scientific articles, official requirements, software representatives and manuals. Designers' current working methods and needs regarding BIM and carbon footprint calculation are surveyed through semistructured interviews with design and calculation professionals, and email inquiries to calculation tool specialists. List of the building design and calculation tools is created by searching in scientific articles that deal with sustainable building design, carbon footprint calculation or tools to perform life cycle assessments (LCA). Some searching in the internet was done as well. Few expert contacts gave hints of used tools.

The closely related concepts like embodied carbon footprint, BIM and industry foundation classes (IFC) are explained in chapter 2. Related standards are compressed and the current official requirements in Finland are listed in the chapter 3. The currently available IFC compatible building design softwares and tools for the embodied carbon footprint calculation are listed in the chapter 4. There is also a short description about how they work. The chapter 5 covers the conducted interviews. The results are given int the chapter 6. After that, the conclusions and recommendations are presented in the chapter 7. Summary of the whole study can be found from the chapter 8.

Scope of the research

The research scope is limited to IFC compatible carbon footprint calculation softwares that can import and eventually also export information without manual interference. The modern data transfer methods without human intervention are cost effective and less prone to errors. Therefore there is no reason to study old fashioned methods like using manual copy paste and tables.

This study does not give a description how to perform an embodied carbon footprint calculation in detail. There is a standard to define the calculation, which can also be used to define whether or not every single method qualifies as official carbon footprint calculation method. This leads to that the question, how to transfer the information required in the calculations from a design software into the calculation software is also out of the scope. The technology to transfer the information between the software is described in the IFC specifications. However, some ideas how the interoperability between the building design and calculation softwares could be improved, are presented.

2 Theoretical background

As the concept of carbon footprint calculation has fairly recently gained more attention, the terminology is quite diverse. This chapter defines essential related concepts such as carbon footprint, LCA (life cycle assessment), IFC (industry foundation classes) and BIM (building information model). Also the €CO2-project is presented as well as what is sustainable building design and embodied carbon footprint of the buildings.

2.1 Background of the research

The European Union has set a goal to move into zero energy buildings by the year 2020 (Vapaavuori, 2008). Such buildings can be built in various materials and construction methods. Traditionally the ecological calculations have concentrated to the usage state of the buildings, but while the building energy consumption approaches zero energy consumption, the effect of embodied greenhouse gas emissions grow more important. At this point it is de rigueur to be able to calculate the embodied carbon footprint of the building materials. Although sophisticated tools for the analysis of life cycle environmental impacts of many goods and services have been developed over the last several decades, the typical life cycle assessment methods are not fully adequate for analyzing the primary energy and greenhouse gas balances of the buildings.

€CO2 – Wood in Carbon Efficient Construction -project started in the end of 2010 and was finished in March 2013. The project focused on carbon efficient wood construction. The project was funded through WoodWisdom-Net and it had 20 partners in five European countries including universities. The main scopes of the project were

1. *to create holistic understanding of carbon efficiency in the full life-cycle of a building,*
2. *to define technical potential and obstacles for the use of wood in carbon efficient construction,*
3. *to develop practical solutions for calculating and optimizing the carbon footprint of different wood construction systems and*
4. *to disseminate scientific results efficiently to relevant stakeholders, including e.g. authorities, regulation developers and construction industry. (Kuittinen et al., 2014)*

The €CO2 project was divided into into 3 thematic levels which are 1 Evaluation methods, 2 Practical solutions and 3 Information platform, as shown in the figure 1. This work belongs to the level 1, in the work package 3 (WP3): ICT methods for evaluation with common data (see figure 1). The focus is on environmental evaluation methods and databases. The aim is to analyse, compare and develop these subjects based on scientific findings and results of analyses from our reference cases. The goal of the WP3 was to develop solutions for the evaluation of carbon footprint and for the management of data in different stages of manufacturing, building and use processes. Furthermore the WP3 acted as a bridge between standardization and development.

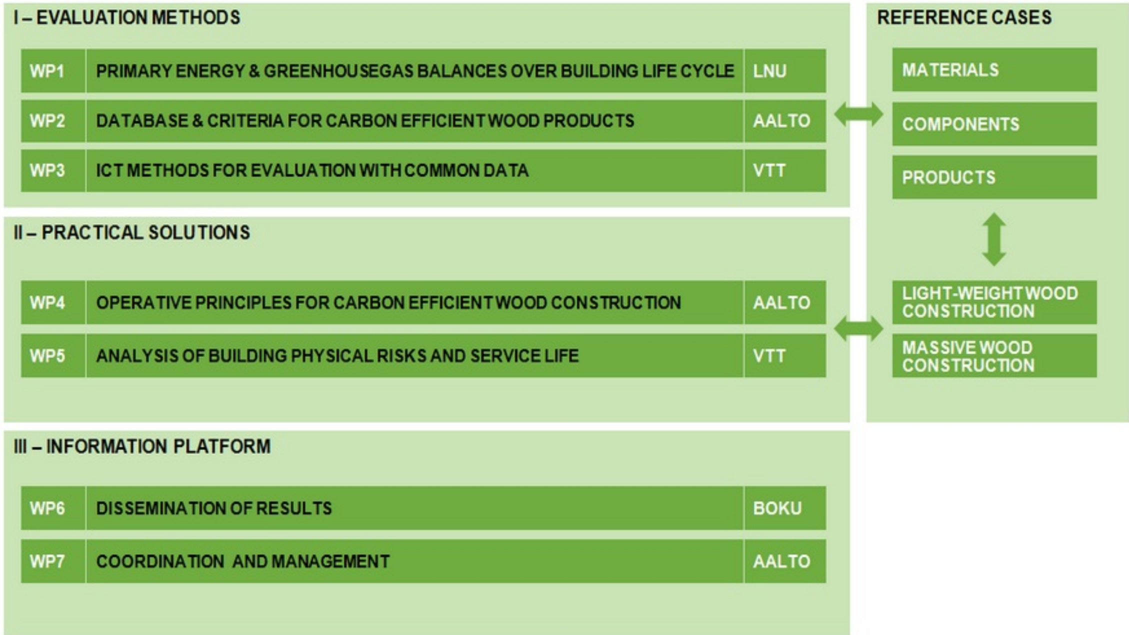

Figure 1: A diagram over the structure of the €CO2 project by Kuittinen (2011). This study was part of the work package 3 on the level 1; ICT methods for evaluation with common data.

2.2 Green building design

The terms *sustainable design, environmental design, environmentally sustainable design, environmentally conscious design*, etc. all describe about the same philosophy of designing physical objects, the built environment, and services to comply with the principles of social, economic, and ecological sustainability. Such buildings use key resources like energy, water, materials, and land much more efficiently than conventional buildings. Within the scope of this work, the term sustainable design will be narrowed into sustainable architecture, forgetting the entire surroundings of the building. Sustainable design definition is based on the standard ISO 14 000.

There are also other approaches into the green building design. For example, Hänninen (2010) has come up with an idea of an organic house (in Finnish 'luomutalo'). In this case energy efficiency would remain being important, but also other aspects – as where the material comes from and what s the energy used for – would be taken cognizance of. Local materials and other building environment decisions can be used to diminish the carbon footprint. It should be ecological, healthy, repairable and recyclable.

As well as Europe, also Finland has committed into reducing greenhouse gas emissions according several agreements. Kyoto agreements and climate and energy politics of EU all pursue towards lower emissions. (Vapaavuori, 2008; Valtioneuvoston kanslia, 2009)

2.2.1 Why go green design

According United Nations Environment Programme – Sustainable Buildings and Climate Initiative (UNEP, 2012) buildings use about 40% of global energy, 25% of global water, 40% of global resources, and they emit approximately 1/3 of green house gas (GHG) emissions which means it is the largest contributor to global GHG emission. At the same time buildings also offer the greatest potential for achieving significant GHG emission reductions.

Azhar's (2011) recent studies indicate that the demand for sustainable building facilities with minimal environmental impact is increasing. Very often it is due the rising energy costs and growing environmental concerns, but also the environmental benefits, the sustainable buildings, or as called green buildings, are kept more healthier for inhabitants. In the Report to California's Sustainable Building Task Force (Kats et al., 2003) the 2% increasing in the designing costs results in life cycle savings of about 20%. Yang (2010) puts it the other way around; in very early phase conducted carbon footprint identification is also the best way to reduce GHG emissions, because 80 to 90% of product design and process design are determined during the design phase. Evolving CO_2 neutral Finland could be started from the buildings, as building construction industry stands for 38% of the carbon footprint of Finland.

It is likely that in the future the environmental regulations will include the greenhouse gas emissions and primary energy use of construction materials as they now include only information about the consumed energy. The indicators are improved to guide decision-makers towards greater resource efficiency. In the construction sector this has a potentially significant effect, as the built environment is responsible for around 35% of all greenhouse gas emissions and 42% of energy use in Europe. For example the National building regulations in Finland will include material efficiency parameters beginning in 2016. (Kuittinen et al., 2014)

2.2.2 Eco-efficiency

Eco-efficiency – sometimes shortened as EE – includes the idea of creating more value with less impact. The World Business Council for Sustainable Development (Brady et al., 2006) defines the term as follow

> *"Eco-efficiency is achieved by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively*

reducing ecological impacts and resource intensity throughout the life-cycle to a level at least in line with the Earth's estimated carrying capacity."

Similarly it can be expressed by the formula

$$eco - efficiency = \frac{product\,of\;service\,value}{environmental\,influence} \tag{1}$$

According Lia et al. (2011) the concept of EE is not common on the building manufacturing branch. There are only few samples: the green building rating system of the Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) in Japan and the EcoEffect method in Sweden.

Huppes and Ishikawa (2005) derives further four basic types of eco-efficiency. They are 1) environmental productivity, 2) environmental intensity of production, 3) environmental improvement cost and 4) environmental cost-effectiveness.

2.2.3 Building life phases

For buildings CEN/TC 350 (the technical committee 350 of European Committee for Standardization, "Sustainability of ConstructionWorks") recommends, according the standard EN 15804 (Suomen standardisoimisliitto, 2014), consideration of four life cycle stages:

1. Product phase, including raw materials supply, transport and manufacture.
2. Construction phase, including transport and construction e installation of on-site processes,
3. Use phase, including maintenance, repair and replacement, refurbishment, operational energy use: heating, cooling,ventilation, hot water and lighting and operational water use.
4. End-of-life phase, including demolition, transport, recycling or re-use and disposal of materials. (Wallhagen et al., 2011)

The first stage can furthermore be divided into several temporal phases:

- the extraction of raw materials,
- the processing of raw materials into prepared building materials and
- the assembly of diverse materials into a ready building (Kuittinen et al., 2014).

Transportation of materials may be involved in all stages (Kuittinen et al., 2014). Similar segmentation can be seen in the figure 2.

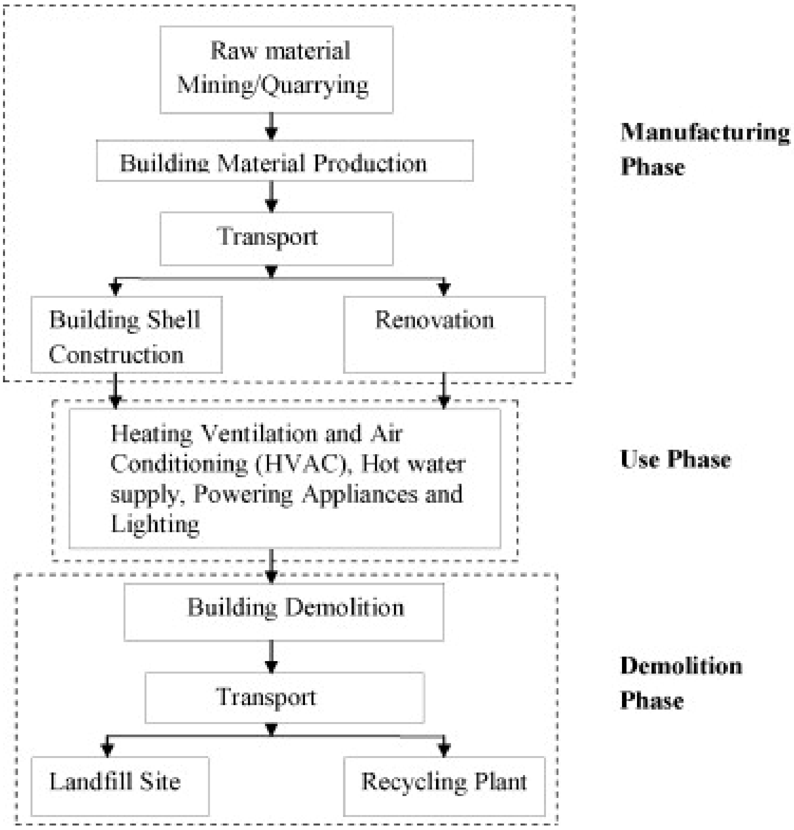

Figure 2: Schema over the four building life phases according Ramesh et al. (2010). Here the Manufacturing phase includes both building material production and construction phase.

The accounting of GHG flows associated with products and materials should be done in a life cycle perspective as shown in the figure 3. In other words, the analysis should consider all inputs (e.g. energy, materials) and outputs (e.g. emissions, waste, co-products) for each stage of processing, from extraction or regeneration through ultimate use, maintenance and disposal.

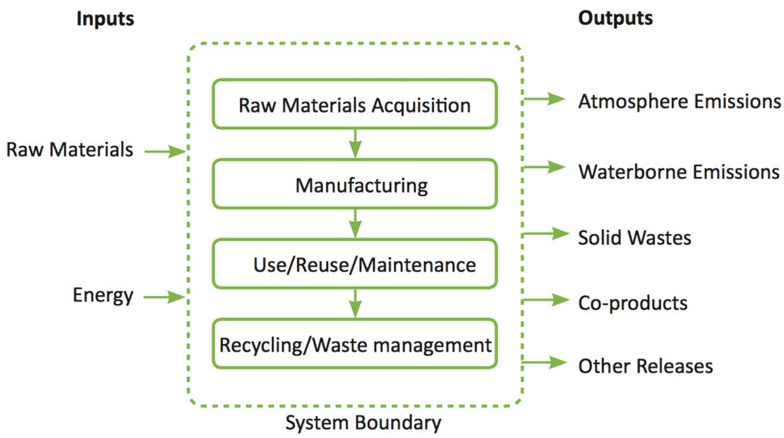

Figure 3: Schematic diagram of life cycle stages, inputs and outputs, according (Kuittinen et al., 2014).

In the €CO2 project (Kuittinen et al., 2014) the result was that in the full life cycle and energy chains for buildings should be considered with broad enough system boundaries so that all significant parts are included. Calculations of building systems are rather complex and sometimes practical simplifications may be required.

2.3 Carbon footprint

Carbon footprint describes the environmental impact of a product or service over its entire life cycle (International Standards Office, 2013). Carbon footprint analysis is an LCA impact category focused exclusively on Global Warming Potential (GWP). It measures the climate change potential of GHG emissions in units of CO_2 equivalent. (Kuittinen et al., 2014) Defining carbon footprint for building materials is not a simple task. Geographic and country-specific differences have significant effects on the carbon footprint. The €CO2 project (Kuittinen et al., 2014) refers specially into wooden materials, but the same implies into other materials as well. For example country-specific energy mixes have an impact on CO2 emissions. This leads into situation, where one fixed database will not work everywhere.

Carbon foot print refers to the spent natural resources and produced GHG emissions over the the life cycle of the commodity. There are several methods that have been proposed to asses carbon emissions over the product lifecycle (Yang, 2010). The term can be divided into two parts: Direct and indirect. The direct carbon footprint describes the direct carbon dioxide emission when burning the fossil fuel in traffic and energy production. It can be controlled directly. The indirect carbon footprint calculates all carbon dioxide emissions related to the products, from their whole life cycle including production and devastation. Sometimes the term of carbon footprint includes also the emissions of other greenhouse gases. A greenhouse gas can be any gas in an atmosphere that absorbs and emits radiation within the thermal infrared range causing the greenhouse effect, such as methane, nitrous oxide, or chlorofluorocarbons (CFCs). The greenhouse gas emissions are associated more with production, while carbon footprints focus on the greenhouse gas emissions associated with consumption.

The origin of the term lays the concept invented in the early 1990s called ecological footprint, which refers to the total area of land required to sustain an activity or population. It includes several environmental impacts and is therefore more complicated ecological indicator. A carbon footprint is usually expressed as a measure of weight, as in tons of CO_2 or CO_2eq per year. The secondary carbon footprint reflects the carbon emissions associated with the consumption of goods and services (Contact Carbon Footprint Ltd, 2012).

Embodied carbon footprint refers to the CO_2 bound into the building materials whereas the operating energy calculation takes into account only the energy for heating, cooling and ventilation of the building used during the building life cycle. In building owners' point of view the assessment reports should be uniform, easy to read and comparable from project to project (Laine et al., 2000).

2.3.1 Carbon footprint generation over the life cycle of building

Ramesh et al. (2010) have encountered that normalized entire life cycle energy use of conventional residential buildings falls in the range of 150–400 kWh/m^2 per year (primary) and office buildings in the range of 250–550 kWh/m^2 per year (primary). The most effective way to reduce this is to reduce operating energy "even if it leads to a slight increase in embodied energy."

The operating energy shows the largest share in building life cycle energy distribution and is therefore the most important area to reduce energy usage. Studies (Ramesh et al. 2010, Laine 2007) estimate that the energy use during the operational phase is more than 80% of the entire carbon footprint considering the entire building life cycle with a life span of 50–100 years. Anton (2012) suppose in colder countries as in Finland up to 95% of the used energy during the total building life cycle energy consumption comes from operational energy. According Wallhagen et al. (2011) in the beginning of the building life cycle the only environmental impact comes from production of building materials. The operational energy then adds the environmental load every year and after about 60 years the impact is the same from materials and from operational energy for the original building. If a building can be connected to energy sources with very low GHG emissions (for example district heating), or it is very energy-efficient, the relative environmental importance of production of the construction materials increases significantly (Thormark, 2002; Wallhagen et al., 2011). Ramesh et al. (2010) amplifies that in their 73 literature case studies from 13 different countries, life cycle energy use of buildings depends on the operating (80%) and embodied (10–20%) energy over the life cycle of the buildings. The other way round, according Wallhagen et al. (2011), embodied energy equals the operational energy in 15–37 years (see figure 4). Demolition has only 1–2% share of the total energy usage (Ramesh et al., 2010). Demolition and end-of-life of materials are seldom included in life cycle studies of buildings because lack of data. This can be accepted due to their low percentage of the total energy usage of the building life cycle.

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2.3.2 Life cycle assessment

Life cycle assessment (LCA) is an analytic method to assess environmental impact of the products (Yang, 2010). It is an evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle. Originally LCA was developed for single products, but there has been a shift in applying it to larger scale

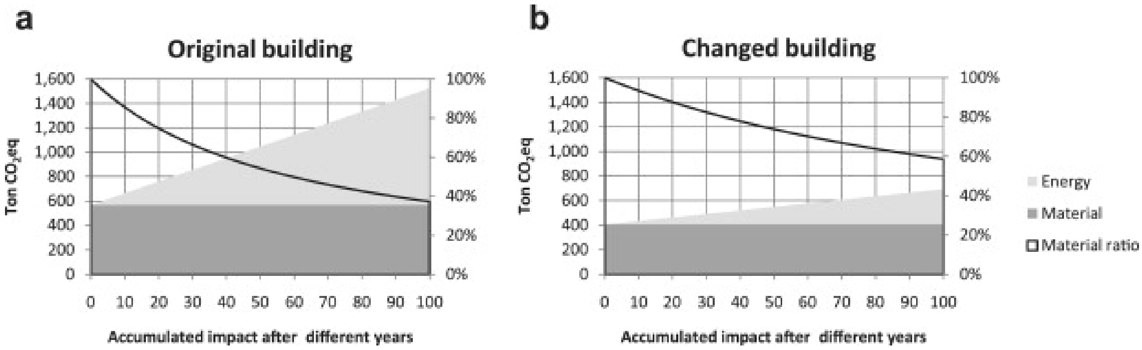

Figure 4: Total CO2eq emissions after different number of building service life years. The curve shows the relative impact of materials in % (right scale). (Wallhagen et al., 2011)

processes. LCA can be used to estimate the possible impacts associated with products, both manufactured and consumed, and to development of methods to better understand and address these impacts. LCA is iterative method. By this far it does not have one single method to define system boundaries (Yang, 2010). The scope of LCA includes only environmental targets, economical and social effects are out of focus. If wider assessments are desired, other tools should be taken into use.

LCA calculation methodology is standardized in the European Standard EN ISO 14040 (2006b) *Environmental management – Life cycle assessment – Principles and framework.* This is the overarching standard and it is also a Finnish national standard. ISO Standards 14041-14043 deal with inventory analysis, environmental impacts and interpretation of the results of LCA.

The four phases of LCA are

1. the goal and scope definition phase,
2. the inventory analysis phase (LCI),
3. the impact assessment phase (LCIA), and
4. the interpretation phase. ((2006b))

The environmental impact of buildings is usually conducted by LCA study. LCA helps the decision-makers in planning and selecting relevant indicators to measure environmental performance. Internally it can be used in process analysis, product evaluation, material selection and construction system comparison. From externally use it can be exploited in marketing, information, education and eco-labelling.

According Jensen et al. (1997) the first LCA type calculations were done in the early seventies. This means LCA has over 40 years of history, but still it is not used widely due to several limitations. The calculation is difficult as the expected life-time of buildings varies. Also data availability and collection is often very difficult.

Various LCA tools have been developed based on qualitative and quantitative methods that can assess building environmental impacts from embodied energy, operational energy, CO_2 emission and other emissions from buildings. These tools have been classified and categorized into five major categories: Detailed LCA Modelling Tool; LCA design Tool; LCA CAD tool; Green Product Guides and Checklist and Building Assessment Schemes.

Life cycle inventory study

Life cycle inventory study (LCI) is also defined in the ISO 14040 and it includes only the second and the fourth phases. LCI does not include the evaluations stage and it should not be confused with the inventory analysis stage of LCA. The LCI of building materials is very laborious and beyond the scope of a normal design project if done manually (Laine et al., 2000).

2.4 Computer aided building modeling

The approach of the computer aided design, shortly CAD, softwares has changed during the years. The older CAD-software were mostly 2D vector based drafting systems. They used to be only designers' tools to simulate product concepts, and therefore we still have plenty of advanced rendering tools, environments, cameras, lightning in them. Modern CAD programs include instead plenty of information about the model itself. They calculate the virtual model from 3D solids and bind amounts of information into the model. Still there are not many tools to help to make the product eco-friendly, or to conduct any lifecycle management. Model-based bills of materials (BOMs) provide faster and more accurate takeoffs for cost estimating, energy analysis, etc. (Jain, 2009)

2.4.1 Building information model

Building information model or modeling (BIM) is a method to create and control information of the building during the entire life cycle. The archetypal model is three-dimensional and includes multiplicity information about the building. The term BIM can be used quite ambiguously, but in this study we reserve it for IFC compatible CAD models.

The SuPerBuildings project (2012) lists as the most important facets of the notion of BIM that

- it covers the entire life cycle of a building project,
- it creates a single information node that simplifies information exchange within the building project, and
- it is a structured collection of construction objects and relationships between them (figure 5).

The BIM for building or other construction includes information about the construction and architectural design, but also about plumbing, electrical installations, flame protection, reservations of the spaces, energy calculation, carbon footprint or any other subject which gives or includes additional information about the building (BuildingSMART, 2012). The BIM gives also an opportunity to carry out performance and other type analysis during the design process (Schueter and Thessling, 2009). It is also said that the first form of a building information model are not the drawings, but the needs the customer has long before the architectural design begins. The model size grows easily huge. In the beginning the idea of BIM was to include all possible information, but the new approach emphasize more the compatibility of the information. Godager (2011) points out, that depending on the purpose of use it is not always convenient to include all possible information into one model.

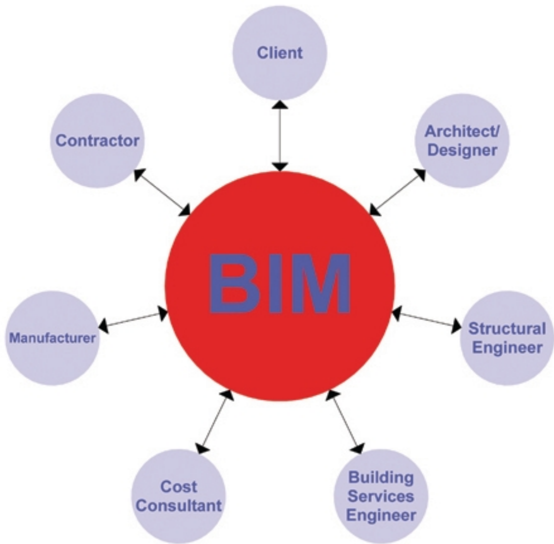

Figure 5: BuildingSMART's (former IAI) vision of the integrated BIM which connects the various project parties by one information model (Puckett, 2011).

An appropriate CAD or BIM tool can control the BIM. There are several programs that enable it. Some of them have functions specially designed for architects, the others are more suitable for further developments or the structures. The softwares are presented later in the chapter 4.

There are several building information model specifications even within AEC industry: Standard for the exchange of product model data (STEP), the earlier mentioned IFC and CIM integration standard (CIS). STEP is an ISO standard 10303, and it is aimed for various industries including automotive and aerospace industries, construction industry and so on. The specifications are represented in EXPRESS language. CIS is an industrial standard for construction and planning industry for steel frame buildings and similar structures. The construction-operations building information exchange (COBIE) is an information exchange specification for the lifecycle capture and it facilitates the delivery of information during planning, design, construction, and commissioning needed by facility owners and operators (East, 2012).

The advantages of using BIM in a building project are evident. Azhar et al. (2008) presents a table of an average BIM Return on Investment (ROI) in selected US projects. The ROI ranges from 40% to 39900% which means BIM is clearly lucrative economic benefits. Advantages from a sustainable assessment point of view include easy accessible and analyzable data from the BIM model, environmental properties included into the data and later the data storage within the BIM (SuperBuildings, 2012).

In Finland Senaatti properties started to require plans in BIM format in 2007 and later in 2012 their requirements were expanded as common building model requirements. The instructions include the energy consumption simulation, which aims to conduct the design Rakennustietosäätiö RTS (2012). Senaatti's directions are now widely used in Finland.

2.4.2 Industrial foundation classes

Computer aided design (CAD) programs as well as other softwares have usually their proprietary, native file formats. To enable data transfer between different CAD programs they will have to understand each other's native formats, or they will have to be able to interpret some common, open file format. In BIM this open format is called industry foundation classes (IFC). The other way round, IFC is on open BIM and counterpoint to this would be proprietary BIM. (BuildingSMART 2012, The Office of Energy Efficiency and Renewable Energy, 2012a)

IFC is an independent, non-party file format for transferring information between IFC compatible softwares. It is an international data transmissions standard, which enables moving the building information model from one program into an other. IFC is developed by an international, american–european coalition of AEC companies (architectural, engineering and construction) called International Alliance for Interoperability, IAI, now knows as BuildingSMART. Also software producers have been involved. The first steps were taken 1995, and in 2012 there was the seventh released version called IFC2x4, or IFC4. BuildingSMART (2012)

The main object of BuildingSMART is to to coordinate improving productivity, efficiency and sustainable development within construction and building management industry. BuildingSMART defines three pillars to support the efficient exchange of information. These are the format (how to exchange), sent information (what is changed) and methods of the exchange (when is it exchanged). (SuperBuildings, 2011)

There is a standard ISO 16739 *Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries* (ISO, 2013) which specifies a conceptual data schema and an exchange file format for Building Information Model (BIM) data.

It applies only to construction and facility maintenance, project structure and component breakdown structures in building engineering, and it does not perceive behavioral aspects of components and other information items. Graphisoft was the first to bring IFC into world wide use with a CAD program. Now several architectural CAD tools are already IFC compliant (Laine et al., 2000).

buildingSMART Data Dictionary

The buildingSMART data dictionary, bSDD (former international framework for dictionaries (IFD) library) is a formalized way to represent a vocabulary (SuperBuildings, 2011). It helps to link the model and various databases with project and product specific data (figure 6). IDF is also known as an standard ISO 12006-3.

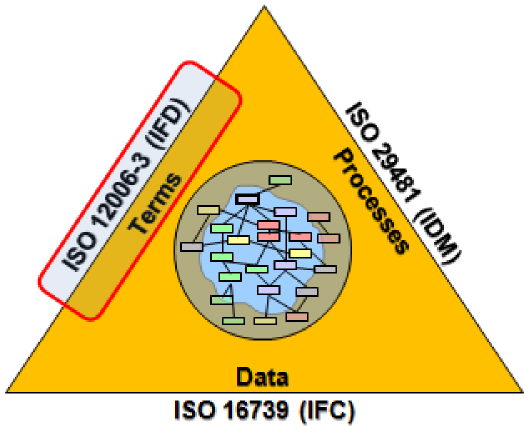

Figure 6: The standard ISO 12006-3, also called IDF is one of the core components of the buildingSMART technology (IFD Library, 2012).

Information delivery manual

The buildingSMART standard for process is described as model view definition (MVD, formerly known as the information delivery manual, IDM). It is a formalized way to express and represent processes and data exchanges (SuperBuildings, 2011).

2.4.3 Green building extensible mark-up language

The green building extensible mark-up language (gbXML) is an open schema that helps applications from disparate vendors to share data. It is specially designed for building properties stored in 3D BIM. gbXML has the industry support of various 3D BIM vendors such as Autodesk, Bentley, and Graphisoft. With the development of integration modules inside the major engineering analysis tools, gbXML has actually become the de facto industry standard schema. gbXML can be used to analyze and manipulate energy aspects of the building including the carbon footprint. (gbXML.org, 2012)

Green Building Studio (GBS) started the gbXML development in 1999. The gbXML schema was released in 2000. In 2008 gbXML was spun-off into a non-profit called the *Open Green Building XML Schema, Inc.* (gbXML.org, 2012).

Several energy analyze software are capable to handle gbXML information. The list includes Green Building Studio, Ecotect and IES. ArchiCAD has an add-on that saves the heat zones of the building information model directly in the right format for other software. (VTT Technical Research Centre of Finland Ltd, 2012)

3 Authoritative operational environment

As construction and building materials and technologies are more and more international issues, also the requirements are regulated with international organizations and standards. In this section the instances, the legislation part and description of the standards are focused to Finland, but they can be applied to Europe.

3.1 Regulative instances

There are several instances that work for developing more effective methods regarding sustainable building. At the organizational level they help to establish effective strategies and methodologies of implementing BIM (Arayici et al., 2011).

There is currently work going on in e.g. the United Nation's Environment Programme's Sustainable Building and Climate Initiative (UNEP-SBCI), ISO (International Organization for Standardization), CEN (European Committee for Standardization) and SBA (Sustainable Building Alliance). In the following chapters the most significant groups working with carbon footprint regulation in Europe and related to this work, are presented.

3.1.1 CEN/TC 350

Technical Committee 350 of the European Committee for Standardization (CEN/TC 350) has developed methods to asses the sustainability aspects of buildings, and standards for the environmental product declaration of construction products. Samples about the working area are the building life cycle descriptions and the new standard EN15804 (SFS, 2014), Environmental Product Declarations (EPDs) that would unite the evaluation methods in Europe. CEN/TC 350 serves under Association Français de Normalisation (AFNOR, 2012a).

There are 24 environmental indicators used by the CEN/TC 350 standards in total. Those include seven environmental impact indicators, ten resource indicators, three waste indicators and four output flow indicators. In the group of seven environmental impact indicators the Global Warming Potential is the same as Embodied Carbon measured using CO_2eq (Anderson, 2012).

CEN/TC 350 estimate the characteristic emissions by segments:

- materials
- building
- usage
- demolition and re-usage (Anton, 2012).

3.1.2 BuildingSMART

IFC is developed by an international, American–European coalition of AEC companies (architectural, engineering and construction) called BuildingSMART International. Originally the organization was called International Alliance for Interoperability, IAI. The name changed in 2005. Building SMART aim to standardize processes, workflows and procedures for BIM. BuildingSMART *"drive the development and active use of open internationally-recognised standards, tools, training and certification regimes to support the wider uptake of Building Information Modelling (BIM) by owners, operators, the Architecture, Engineering & Construction (AEC) and Facilities Management (FM) industries across the buildings and infrastructure sectors."* (BuildingSMART, 2012)

3.1.3 Green Building Council Finland

Green Building Council Finland, FIGBC (2014) is a Finnish association that works to improve co-operation and raise the level of the common sustainability calculation methods in the area of build environment. FIGBC strives to introduce sustainable methods as an organic part of the operations on the building and construction branches. The association produce information to aid the members, and applies international methods to be used in Finland. They also offer some tools to other parties, like online energy efficiency calculator for one family house owners. The members of FIGBC consist of owners, constructors, designers and so on, both commercial and industrial parties.

3.1.4 The Sustainable Buildings and Climate Initiative by United Nations Environment Programme

The Sustainable Buildings and Climate Initiative, UNEP-SBCI, is an initiative by the United Nations Environment Programme (2012). It consists of major public and private sector stakeholders in the building area, who work to promote sustainable building policies and practices worldwide. UNEP-SBCI works to raise environmental awareness in building sector, develops tools and establish baselines for life cycle approach.

3.2 Standards and other specifications

There are several standards and methods involved in the environmental building life cycle calculation and LCA definition. The regional requirements have a great significance on which methods are mostly used. In the following chapters the methods mentioned in this study are listed and presented shortly.

In the final report of the €CO2 project (Kuittinen et al., 2014) the experts claim that *"the current standards that are related to the environmental assessment of buildings (e.g. EN 15978) set good common rules, but are not practical enough to be applied during the* *design phase of buildings, and thus they can hardly be used in support of early decision making."* New agile standards are required for iterative decision making during the design and construction process. In the following chapters there are the most important standards regarding carbon footprint calculation.

3.2.1 EN 15643

The standards of EN 15643 (2012) are framework level standard designed to provide various principles and requirements for the assessment of buildings. All its parts regulate environmental, social and economic performance taking into account technical characteristics and functionality of building. For new buildings it is over their entire lifetime, and for the existing buildings over the remaining service life and the end of life stage.

The first part, EN 15643-1, provides the general guidelines for sustainability assessment of buildings. The second part, EN 15643-2, provides the specific guidelines for the assessment of environmental performance for buildings. These two are the most important regarding environmental evaluations as embodied carbon footprint calculation.

3.2.2 EN 15804 and EPD

One of the latest work of CEN/TC 350 (AFNOR, 2012b) is the standard EN 15804. It is a building product level standard that provides the core rules for the creation of EPDs (environmental product declarations) for building products and materials.

Separate product categories will later get their specific regulations. For example for wood products there is already the standard EN 16485 (2014) for EPD's of wood and wood-based products for use in construction.

3.2.3 EN 15978

Whereas the EN 15804 (2014) is a product level standard, the standard EN 15978 (2011) describes the calculation method of the greenhouse gas emissions caused by all stages of the life cycle at the building level. The emissions are transformed into carbon dioxide equivalents, CO_2eq. The standard defines system boundary for buildings and the procedure to be used to calculate the LCI, life cycle inventory. The figure 7 shows the system boundary of EN 15978 compared with the system boundary of the calculation tool called eTool (2013). EN 15978 also describes how the results should be presented and informed. The report from the method gives possibility to compare different calculations. The interpretation and value judgments of the results of the assessment are not within the scope of this European Standard. (AFNOR, 2012b)

The method is based entirely on LCA, hence a reliance on the later in this work presented standards ISO 14040, 14044 and 14025. The assessment includes all building related

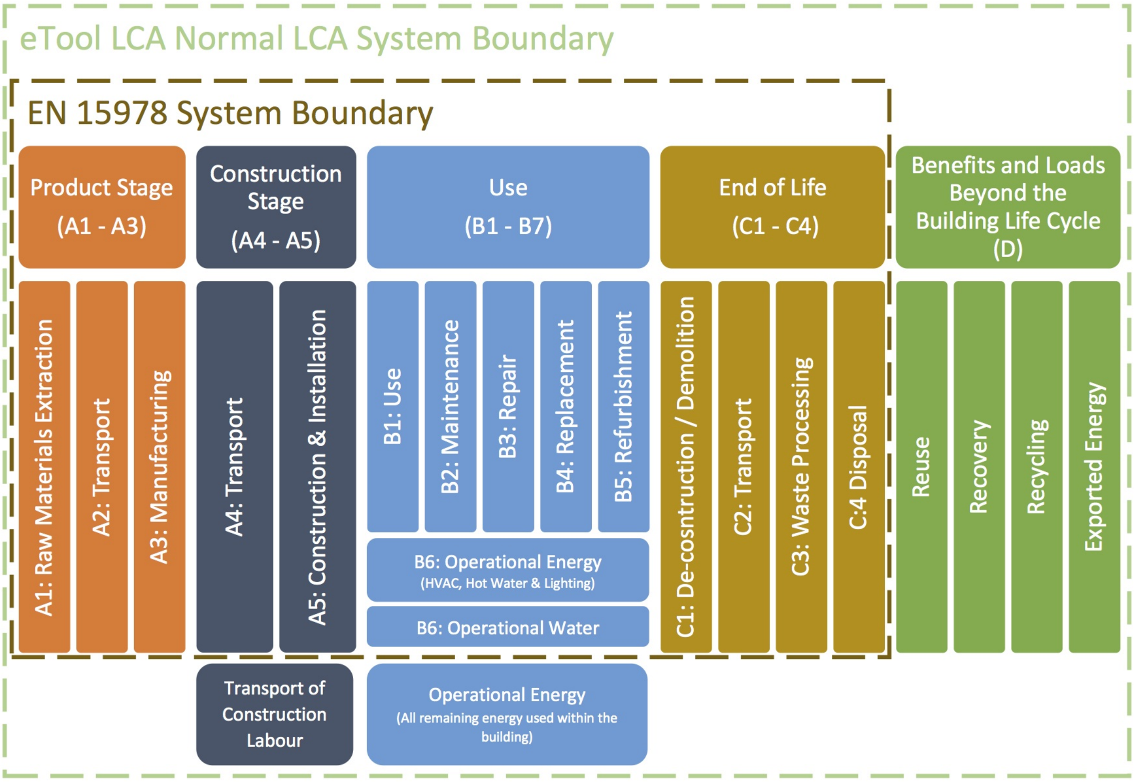

Figure 7: Comparison between EN 15978, calculation method for assessment of environmental performance of buildings, and calculation tool called eTool LCA's normal system boundary (eTool PTY LTD, 2013).

construction products, processes and services, used over the life cycle of the building. The calculation data for this method comes from EN 15804, the EPDs and their information modules. (AFNOR, 2012b)

3.2.4 ISO 14000 family

The ISO 14000 (International Standards Office, 2012) is a family of standards regarding various aspects of environmental management (table 1). The standard family, presented in the table 1, provides tools for identifying and controlling the environmental impact. It also gives companies and organizations a possibility to improve their environmental performance. There are standards that focus on environmental management systems (ISO 14001 and ISO 14004). Rest of the standard family focus on specific environmental aspects such as life cycle analysis, communication and auditing. They all provide tools to conduct the calculations of EN standards.

3.2.5 ISO 14025

The standard ISO 14025 (2006a) is a Type III environmental declaration, and also commonly known as Environmental Product Declaration (EPD). It is used to create the en-

Table 1: A table over ISO 14000 standards family. They are standards regarding various aspects of environmental management. (International Standards Office, 2012)

14001 & 04	Environmental management systems
14010, 11, 12, 15	Environmental auditing
14020, 21, 22, 24, 25	Environmental labelling
14031, 32	Environmental performance evaluation
14040, 41, 42, 43, 48, 49	Life cycle assessment
14050	Vocabulary
14061, 64	Guide

vironmental declaration to any product where as the earlier mentioned EN 15804 is for building products. EPD is a format to provide relevant, verified and comparable information about the environmental impact of especially goods and services.

3.2.6 ISO 14040

The international standard ISO 14040 (2006b) is the framework for the LCA calculation of products and services. Even though it covers the entire life cycle, it does not describe any calculation technique or methodology in detail. The intended application of the results is considered during the definition of the goal and the scope, but the application itself is outside of the focus of this standard. The standard ISO 14040 is also a Finnish national standard. (SFS, 2013)

3.2.7 ISO 14044

In 2006 the previous standards ISO 14041, ISO 14042, and ISO 14043 were integrated, harmonized, and replaced by ISO 14044 (2006c), which sets the requirements and guidelines for the life cycle assessment. This new precise standard ISO 14044 concern all of the specific four phases of an LCA; definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase and the life cycle interpretation phase. It also involves reporting and critical review of the LCA, limitations of the LCA, relationship between the LCA phases, and conditions for use of value choices and optional elements (ISO, 2006b).

3.2.8 ISO 14064-3

For the principles and requirements to conduct or to manage the quality of greenhouse gas (GHG) assertions there is the standard ISO 14064-3 (2012; 2006d). It defines some requirements for selecting methods to measure chosen concepts.

3.2.9 ISO/TS 14067

The technical specification (not yet proved standard) ISO/TS 14067 (SFS, 2013) gives guidelines, requirements and instructions for calculation and communication of the carbon footprint (CFP) of a product. It provides procedures to support both transparency and credibility and also to allow for informed choices. ISO 14067 addresses only the impact category of climate change and offsetting of the carbon footprint is out of its scope. The development or the adoption of CFP-product category rules (CFP-PCR) is part of the standard.

The reason to create this standard was to harmonize the existing calculation methods and to create a worldwide consensus regarding CFP calculation. The common instructions and principles can be used to a wide range of products and services. It is supposed to become a standard after some user experience has been gathered. The procedures are based on the life cycle analysis standards ISO 14040 and ISO14044 and into environmental labels and declaration description standards ISO 14020, ISO 14024 and ISO 14025. (ISO, 2013)

3.2.10 ISO 21930

According the standard ISO 14025 (2006a) EPD is a verified document that reports environmental data of products based on life cycle assessment (LCA) and other relevant information. The standard ISO 21930 (2007) explains the environmental labels and declarations for building materials respectively.

3.2.11 PAS 2050

Publicly Available Specification (PAS) 2050, published by the British Standard Institute BSI in 2011, is a simplified LCA. It offers a method for assessing the internal life cycle greenhouse gas (GHG) emissions of goods and services. According Yang (2010) helps to evaluate alternative methods of producing raw materials and devise programmes to reduce GHG emissions. It does define the system boundaries, but it does not recognize specific issues related to individual products.

3.2.12 National Building Code of Finland

The new National Building Code of Finland (NBCF) by The Ministry of the Environment (2012) includes both binding and advisory parts. The technical regulations and instructions, which are given by decree, are obligatory. They concern the construction of new buildings. They are applicable also to renovation and alteration works to some extent. NBCF does not set exact requirements on building technology or materials. It takes notice about the amount of used energy and how the primary energy is produced instead. In

Finland the major part of primary energy is used for heating, lightning and cooling. By reducing these, also the carbon dioxide exhaust will decrease (Betoniteollisuus ry, 2010).

3.3 Current Finnish regulations

At the moment, 2014, there are not any mandatory requirements for LCA calculations of buildings, or other CO_2eq limits to aspire. The standard EN 15804 (SFS, 2014) is the only one applicable instructions for the calculations. As a part of the environmental leading programs (Green Building Council Finland, 2014) has created a bunch of indicators that decrease the stress falling over environment, maintain and increase the value of the property, reduce the maintenance cost and improve the welfare and comfort of the users. These indicators are open for comments and they will be printed in the end of November 2014. The new National Building Code directs the used energy into more renewable sources. However, this regulation does not cover the carbon footprint of the materials (Pekkarinen-Kanerva, 2010). At the moment for example Rakennustietosäätiö RTS (2012) defines environment analysis as an evaluation of the energy consumption, raw material consumptions and emissions of the building as well as the expected life length of the building.

4 Carbon footprint calculation methods and tools

In this chapter the carbon footprint calculation approaches and methods are observed in more detail. The software presentation includes the found tools that are available at the moment. Those calculation tools that does not fill the requirements are listed separately in the end of the chapter.

4.1 About life cycle assessment

Even though carbon footprint calculation relies heavily into life cycle assessment (LCA) calculation, they are not the same. To understand the working environment, here is a short peek into LCA calculation. LCA is an internationally standardized method ISO 14040 (2006b) to assess the overall environmental impacts caused by a product or service, and it can also be used to look at only Greenhouse Gas emissions. A full formal LCA analysis according the standards ISO 14040 and ISO 14044 (2006b; 2006c) includes four phases.

1. Goal and scope definition describes the purpose of the study, the system boundaries of the analysis, and the functional unit used for assessment and comparison.

2. Inventory assessment quantifies the inputs and outputs of mass and energy attributable to processes occurring within the system boundaries.

3. Impact assessment characterizes the effects of these inputs and outputs considering resource depletion, human health, ecosystem quality, and climate change.

4. Interpretation of the inventory and impact assessment results seeks to identify significant conclusions, recommendations and implications for decision-making.

It is said that LCAs are only useful when used to compare options.

According Kuittinen et al. (2014) *Life Cycle Assessment (LCA) is an analytical framework for determining the environmental impacts resulting from processes, services and products.*

The scope of an LCA evaluation should include information about the purpose of the use, reasoning why the evaluation is done, target and whether the results are meant to be used in public. The process should be defined so well that the width, depth and details are good enough for the desired results. The exact calculation method may vary, but Ramesh et al. (2010) consider that as long as the LCA evaluation method is transparent and follows the standard ISO 14044 it can be accepted as an LCA method. The decisions taken during the evaluation should have scientific approaches. If this is not possible, some other aspects can be used. If any other appropriate approach is not possible, decisions may be based on value choices. It is very important to comprehend that comparing the results of different

LCA studies is only possible if the assumptions and context of each study are equivalent (Ramesh et al., 2010). There are studies, e.g. Feldmann et al. (2012), that demonstrate that there is discrepancy in the results of LCA calculations done in two different methods. This could be seen when comparing the results with one sample building.

Ramesh et al. (2010) remind that LCA is very dependent on the primary sources of the energy and conversion efficiency of the materials' production processes. For example if energy source is changed from fossil to renewable, environmental impact changes drastically.

4.1.1 Approaches into life cycle assessment

There seems to be several ways to categorize the carbon footprint calculation approaches. Differences between the approaches can be found in focus, boundary definition and used data. The two main approaches to the carbon footprint calculation can be called process analysis (PA) and environmental input-output (EIO) method. (Jain, 2009; Kuittinen et al., 2014)

The process analysis (PA) is bottom-up method also known as attributional LCA. PA based LCAs do not take into account many second or more order impacts. It is more for understanding from cradle to grave life cycle of one individual product handled as one functional unit. The functional unit identifies and describes unit processes and scales them to required in- or output. The positive sides of the approach is that it solves allocation issues and match up with accounting. This method uses average material data. (Jain, 2009; Kuittinen et al., 2014)

The environmental input-output (EIO) analysis is a top-down method, which simplifies the calculation. This method is also known as consequential LCA. In EIO analysis the input-output tables provide a picture at the sector level. It uses marginal, more product specific data representing the consequences of a small change in the output of goods and services. Just focusing on marginal data narrows the set of data required, since indicators that do not change as a result of the intervention do not have to be known. The system boundaries are typically defined to include the activities contributing to the environmental consequence of the change regardless of whether or not these changes are within or outside of the cradle-to-grave system being investigated. With consistent environmental account data it can give a comprehensive and robust information about the carbon footprint. (Jain, 2009; Kuittinen et al., 2014)

Using both methods simultaneously gives a detailed and yet comprehensive analysis. In lower order stages PA will give enough details and accuracy while the higher-order requirements are covered by the input-output method. It is then called Hybrid-EIO-LCA method. (Jain, 2009)

The standards do not deal with the different approaches very much. The Appendix

A.2 of ISO 14040 (2006b) mentions that *"Two possible different approaches to LCA have developed during the recent years. These are*

(a) one which assigns elementary flows and potential environmental impacts to a specific product system typically as an account of the history of the product, and

(b) one which studies the environmental consequences of possible (future) changes between alternative product systems."

As carbon footprint calculation is part of the LCA calculation, the approaches into LCA calculation can also be applied into carbon footprint calculation.

4.2 Carbon footprint calculation methods

Carbon footprint calculation can be conducted in several different ways. In the following a short peek into some possible methods.

4.2.1 Traditional carbon footprint calculation

Carbon footprint of the materials can be calculated based on the quantity take offs of the design model. However these traditional manual calculations based on the quantity tables are unreliable. The results should be reproducible but as long as the methods and selecting the information for calculation is based on the decisions of evaluator, this is not the case (Kats et al., 2003). If the evaluation is done based on 2D drawings, there is always a lot of interpretation in the picture. Modeling the 3D thermal model for the energy calculation based on 2D drawings is usually manual work. The resulting model is often simplified and construction details are taken arbitrary into account (Bazjanac, 2008). Changes in the model are not easy to notice and evaluation takes time (Torcellini et al., 2004). Still this is very common way to conduct the calculations and for example The Helsinki Metropolitan Area Council (Rakennustietosäätiö RTS, 2012) considers the technical installation models and the bills of quantities of the construction parts to be good information sources for environmental analysis in their National Building Code of Finland.

4.2.2 More advanced carbon footprint calculation

According Bazjanac (2008) the principles for a good evaluation include elimination of inappropriate human intervention. Input should be as automatic as possible. The traditional calculation methods are too slow and ineffective in modern world. If the models are prepared accurately and the information is transferred automatically into more automatic evaluation system, the time saving is 70–80% compared to manual calculation.

Laine et al. (2000) mention that a systematic carbon footprint evaluation cannot be conducted if the results of LCA calculations are not clear and transparent. For the sake of transparency the inventory and evaluation methods in use should be well known and commonly accepted.

4.3 Exploiting building information model in evaluations

By this far the CAD-compatible LCA tools are not as accurate as specific LCA tools, states Morbidoni et al. (2011) in their paper. They seem to be good help in design phase, but the results are not accurate enough for official evaluations. Many of the LCA tools are created for dedicated softwares. And they are therefore not usable for large target group, and are not openly documented. The use of BIM appears to be accelerating, but the best practices should be developed. For example Bentley (Sokolov and Crosby, 2011) advice the designers to prepare their models carefully: Prior to the analysis, the design model must have proper, accurately modeled geometry.

Since BIM allows for multi-disciplinary information to be superimposed within one model, it creates an opportunity to conduct ecological analyses accurately and efficiently as compared to the traditional methods. This could save substantial time and resources. BIM software has the advantage of being up to date during the entire design process and give instantly more information compared to manual data capture. (Azhar, 2011)

Bazjanac (2008) writes that the information about the energy usage evaluation should be delivered to all parties during a project. The same principle could be applied to carbon footprint calculation as well.

4.3.1 Problems creating a valid model for the calculation

Regarding ecological calculation, every part of the building has its own affect to the final calculation. The building consists of smaller and bigger sections, and their ecological weight per dimension varies. Some sections are large and they weight therefore more in the calculation. Some other parts might be smaller by mass or volume, but they have larger ecological footprint of the used material and therefore they should be modeled more carefully in order to maintain calculation result accurate enough. When it comes to carbon footprint of the building, the important building parts are foundations, base floor and earthwork. One problem with this, when considering the final calculation, is that an architect less often designs the entire yard.

The model should be precise enough to give a good calculation result. Melvasalo (2012) comments, that it depends a lot of the design purpose of the building model what means precise modeling. The model can be optimized regarding the calculations, or it can be as the architects produce the model in real life. Ideologically they are the same but in practice these two models are not similar.

4.3.2 Exploiting industrial foundation classes in the calculation

LCA calculation process over the whole building is exhaustive task. Within AEC industry related softwares, the integration of LCA tools with BIM is one of the promising development areas. Jrade and Abdulla (2012) found out, that the integration of LCA and BIM using IFC as the data exchange standard was a working combination. The design professionals could use tools familiar to them (BIM software and Microsoft Excel) and repeat the steps when needed. No difficult programming was needed, but necessary APIs (Application programming interface) has to be built into the BIM environment to make the LCA output more interactive and user-friendly.

4.4 Architectural building design programs

Architects use specific architectural CAD softwares and many of them can be regarded as BIM software. Worldwide there are local differences, which software is the most commonly used. There are only a few large softwares. The most popular BIM softwares are ArchiCAD, AutoCAD Architecture aka. ADT and Autodesk Revit. Also AllPlan and Vectorworks are widely used. The Finnish architectural building designers use also local softwares called CADS and Vertex. The softwares are listed shortly in the table 2. All these mentioned softwares create more or less IFC compatible BIM model of the building. The information for the LCA calculation and specific embodied carbon footprint calculation could be exported in a way or another. The environmental calculation itself is usually done in a specific calculation tool as the design software do not include advanced calculators.

Table 2: The most common IFC compatible architectural building design softwares used by architects in Finland.

Software	**Description**
ArchiCAD	Architecture design software by Graphisoft, IFC 2x3 compatible
AutoCad Architecture	Architecture design software by Autodesk, IFC 2x3 compatible
Revit Architecture	Architecture design software by Autodesk, IFC 2x3 compatible
Vertex BD	Building design software by Vertex, IFC 2x3 compatible

4.4.1 ArchiCAD

ArchiCAD is an architectural BIM software developed by Hungarian Graphisoft SE, today owned by Nemetschek. The history of the first 3D building CAD starts from 1982, and the first BIM version dates back to 1987. Originally the software was developed on Apple Macintosh platform, and still it is the only one of the big architectural softwares that works both on Windows and Mac. Today the software is used worldwide and it has over 20 language versions and even more localized versions. Many of the developers are architects which can be seen in the software as well. Apart from 2D and 3D design, also the visualization is taken a bit further with built-in rendering features. (Graphisoft, 2014)

ArchiCAD is based on parametric objects technology. The building structures are created with various objects directly in three dimensional space, from where any of the 2D drawings and other information is projected. Technologies used in ArchiCAD are geometric description language (GDL) for components, application programming interface (API) and open database connectivity (ODBC) for third party add-ons. Graphisoft has been involved in creating the IFC standard from the beginning. ArchiCAD is fully IFC compatible, and can import and export also traditional DWG and DXF files among others. (Graphisoft, 2014)

ArchiCAD Start Edition, or ArchiCAD SE is a light version of the full ArchiCAD. It creates a complete BIM model and it is suitable for smaller scale architecture practices. From the latest versions ArchiCAD SE 2013 lacks the IFC compatibility; both SE 2011 and 2013 have it. (Bojar, 2005)

4.4.2 AutoCAD Architecture

AutoCAD Architecture, former AutoCAD Architecture Desktop (ADT), is a specific architectural version of widely used AutoCAD software. The first version of AutoCAD meant for technical 2D drawing was released in 1982, and the first architecture specific edition came out 1998. The power of AutoCAD can be seen in the usage of it's formats; DWG and DXF files are de facto formats in 2D drawing exchange. (Autodesk, 2015)

Originally it was a 2D drafting software and originally the technology was based on vector graphics. The latest versions include also surface and solid modeling possibilities, modifiable objects and rendering engine for the visualization. As a heritage from the older version, AutoCAD Architecture still has the command line in the user interface. Autocad Architecture, or ACA, works only on Microsoft Windows platform. (Autodesk, 2015)

4.4.3 Revit

The development of Revit started in 1997 in Massachusetts, USA by Charles River Software. Autodesk bought the software in 2002. Whereas for example ArchiCAD uses parametric programming, Revit's components are created with a graphical family editor. Revit has a parametric change propagation engine that relies on context driven parameters. That enables the relationship between the components to be locked, a feature that keeps the model connected and documentation coordinated. There are several versions of Revit for different purposes, Revit Architecture, Revit Structure, Revit MEP etc. (Autodesk, 2015)

The light version of the software called Revit LT cannot be purchased with any add ons. This means, the cloud service that enables carbon footprint calculation is also unavailable for the LT version. (Leinonen and Syvälahti, 2012)

4.4.4 Vertex Building Design

The Finnish company Vertex Systems Oy has started the business of computer softwares for industrial use in 1977. Vertex software family for building design includes Vertex BD (building design) software and Vertex DesignStream (Product Data Management, PDM) software. They are meant to cover customer specific order-supply chain of a homebuilding company which means all extra data transitions between softwares are minimized. The system is mostly used within prefabricated house companies as they can easily connect the design into production. Vertex is based on an intelligent entity model. It's parametric and feature based technology is quite common modeling method in mechanical softwares. (Vertex Systems Oy, 2015)

4.5 BIM compatible carbon footprint calculation tools

There are several softwares that enable LCA or carbon footprint calculation for building materials. The only problem is that into most of them the information has to be fed manually. The important connecting link between calculation software and design tool, such as architectural software, is missing (Laine et al., 2000). Over ten years ago there was already several interoperable software tools that could provide information needed in the LCA (Reinikainen and McGrath, 2012). But for this study, no well BIM connected LCA or carbon footprint calculation softwares could be found.

Earlier in €CO2 project (Kuittinen et al., 2014) the scientists have come up with the conclusion that it is not convenient to develop separate calculation software, but to improve the existing programs so that they manage the calculations. Yang (2010) claims that the current tools integrated with CAD systems require complete information before they can produce the calculation. In concept design phase the information is not complete for extensive analysis.

Under the following titles there is listed first the only software that already fills the criteria of this study (BIM compatible and calculates carbon footprint). Under separate titles there are then the softwares that are meant for the right type of carbon footprint calculation, but the information must be fed in separately (usually in due form table), not utilizing IFC data transport. In the last chapter there are the softwares that do not fill deny of the criteria of this study.

Description of every software includes at least about how to material information is transferred into calculation software, how is the information analyzed and, if possible, which databases are used. The softwares are in alphabetic order under each title.

4.5.1 BSLCA

Olof Granlund Oy (Laine et al., 2000) has developed a tool called BSPro COM-Server, BSLCA, for making it easier to connect IFC files with calculation tools. The aim was to create a tool to take ecological aspects into account already in conceptual phase. The BSLCA connects the designed objects and structures to actual products and layers of building materials. It also handles energy consumption data. The product and structure libraries are linked to the material database. Whenever new information is available, it can be added into the database.

BSLCA gives the environmental profile of the building. This profile shows clearly which alternative building parts or systems produce the most significant environmental loads. It is a useful tool for building owner in decision making at different stages of the building life cycle and also in steering the design and construction process towards ecological and sustainable solutions. (Laine et al., 2000)

The implemented characterization and weighting methods in the tool are: Swedish EPS (environmental priority strategy), DAIA (decision analysis impact assessment) and Ecoindicator95 methods (Laine et al., 2000). The characterization factors for a period of 100 years is used in all methods. The emissions are given in CO_2-equivalents. In the beginning the data can be handled at building level using square meter based data, but later exact equipment data can be used. The user may navigate on different levels of the building hierarchy which makes it possible to analyze the ecological impacts of alternative design cases on different levels.

BSLCA might have been a promising carbon footprint calculation tool, but the software development was discontinued due to lack of interface update not depending on Granlund (Reinikainen and McGrath, 2012).

4.6 Other carbon footprint calculation tools

Into this category are read the softwares that at the moment can in many cases transfer the information from the design software most often as a table in due form. The softwares do calculate embodied carbon footprint, but the problems with selecting data for the calculation exists. These tools are also listed in the table 3.

4.6.1 Athena EcoCalculator and Athena Impact Estimator

Athena Sustainable Materials Institute (2014) provides several free softwares for construction professionals. They all are aimed to help to take the right environmental decisions already in the conceptual phase when the the most critical decisions are made.

Athena Impact Estimator (IE), a stand-alone program, provides a cradle-to-grave life cycle inventory profile for a whole building. The IE imports bill of materials from any

CAD program. The user can customize the assemblies and if needed, the used energy consumption can be included into the calculation. The structural assemblies are manually fed into Excel spreadsheet in total square feet. The results include embodied fossil energy use and several other impact measures like global warming potential, acidification potential, eutrophication potential, and smog potential. The results take into account life cycle stages. (Athena Sustainable Materials Institute, 2014)

Athena EcoCalculator (Athena Sustainable Materials Institute, 2014) gives designers a faster opportunity to estimate environmental impacts. It is the simplified, Excel variant of The Athena Impact Estimator. User is restricted to use only pre-defined assembly and envelope configurations. There are two versions of the EcoCalculator, residential and commercial. The commercial version is additionally separately customized for high-rise and low-rise. If needed, the operating energy can be included in the building LCA.

Both of these softwares are defined for North American regions. The Impact Estimator and EcoCalculator use data from Athena's own datasets and from the US Life Cycle Inventory Database.

4.6.2 €CO2 Wood House Calculator

Created during the €CO2 project (Kuittinen et al., 2014), the €CO2 Wood House Calculator is a simple table format tool for estimating the carbon footprint of wood-frame structures. The background data can be modified and environmental product declarations data can be added into the calculator. However, at the moment there is only a beta version available and it works only on a narrow segment, wood structures.

4.6.3 ENSLIC

In the project called Energy Saving through promotion of Life Cycle assessment in buildings (ENSLIC), nine of the European Union countries have been working with developing guidelines and examples on how LCA can be used as decision support in early design phases (Malmqvist et al., 2010). They have created an Excel tool which calculates energy use and CO_2 equivalents from both operational energy and building material production.

4.6.4 eTool LCA

eTool LCA is a web based tool for streamlined LCA calculations of the built environment created by eTool PTY LTD (2013). It should help the designers to improve the quality of design. The software measures the embodied and operational carbon, energy, cost and GHG emissions of buildings to promote a sustainable, low carbon design.

Currently there are only two main LCI data bases in eTool (2013). The other one is an Australian data base and the other an international data base from Bath university called ICE. Others might be added in near future. eTool is one of the tools that enable product EPD upload into LCA tools (eTool PTY LTD, 2013). Bruce (2012) adds that at the moment adding EPD's into the software is fairly difficult, but the developers of eTool hope to solve the problems soon and so that the users could do it by themselves. This would make it easier to use the exact right material information instead of large database averages.

eTool is not yet BIM integrated, but according their representative Bruce (2012) the future versions are scoped to include BIM integration. One possible format is gbXML. They have had discussions with the local the Graphisoft distributor about ArchiCAD export option into eTool. This way, it could be a promising calculator in the design phase.

4.6.5 GaBi

The GaBi software is one of the oldest LCA calculation tools available and it can be used to conduct carbon footprint calculations as well. It is developed by the Institute for Polymer Testing and Polymer Science at the University of Stuttgart in cooperation with PE Europe GmbH PE International (2012) starting from 1990. It is a system for balancing complex and data-intensive process networks and life cycle engineering EERE (2012c).

GaBi uses partly its own database; the experts from different fields produce calculation data for various purposes. The processional version of GaBi includes approx. 650 sets of (cradle to gate) data based on information from specialist literature and industry. According Anton (2012) some database values are country specific. The data sets include pre-chains to various materials, provision energy, end of life, disposal and processing with. (EERE, 2012c)

Information is fed in table format into GaBi (Anton, 2012). GaBi follows the norm CEN/TC 350 published in summer 2012. GaBi enables consideration of different cost factors connected to the processes or the lifecycle of products. GaBi makes a parallel analysis of environmental problems in product life cycles according to ISO 14040 and optimizes the production sequences from an economic point of view (EERE, 2012c). GaBi has an improved scenario analysis which enables lifecycle iteration for build, use and end-of-life phases. GaBi is a Windows software, but it can be used on Mac through a Windows emulator or via a parallel platform PE International (2012).

In the GaBi database content there are most of the major Impact Assessment methodologies such as TRACI 2.0, CML, Ecoindicator, Ecological Scarcity Method (UBP), EDIP, USEtox and ReCiPe, but adding an own methodology is possible as well (EERE, 2012c).

4.6.6 Gaia Footprint

Gaia Footprint is not a software, it is a service that provides information like carbon footprint calculations and LCA assessments. The calculations of Gaia follow the greenhouse gas protocol approved by World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD).

4.6.7 IES-VE

Virtual Environment is an online software is actually a suite of integrated building performance analysis tools created by Integrated Environmental Solutions (IES). Estimations can be calculated for energy usage, carbon emissions, thermal analysis, heating and cooling load evaluation, and airflow evaluation. The lighting functions can create solar analysis, daylighting assessment, and LEED® Daylight Credit analysis. According Azhar et al. (2009) the value and cost analysis functions of IES-VE include life cycle assessment and lifecycle cost analysis, but this feature could not be confirmed by other sources. IES-VE has direct plugin to Revit and SketchUp, but common BIN connection is missing.

4.6.8 Ilmari

Ilmari is an online carbon footprint and LCA calculation tool created and developed by VTT Technical Research Centre of Finland Ltd (2014). The information about building construction materials is imported as an Excel table extracted from the IFC model, or manually from the bills of quantities. Before the calculation can be conducted, the construction types have to be defined separately. This is an extra step as in BIM software the the construction types are already defined. Ilmari uses VTT's own database. The calculation itself fulfills the criteria of the study, but the information import in table format makes it less directly BIM compatible.

4.6.9 SimaPro (CIRCE)

SimaPro is a widely used professional tool to develop LCA studies of products, activities and services. The databases and the several impact assessment methodologies included in SimaPro makes it suitable to carry out also LCA of buildings even though it is not specifically designed for that. It offers interactive results analysis, tracing results back to their origins. It also presents a weak point analysis, using the process tree to identify any "hot spots". SimaPro follows the standard ISO 14040 and it can be used to develop parametrized modeling with scenario analysis.

SimaPro does not have an own database, it uses Pre4, FRANKLIN US LCI, IDEMAT, BIWAL250 and FEFCO. The databases can be edited and expanded if needed. SimaPro uses the same CML information source as GaBi as long as more detailed information is not available. The information is fed into SimaPro by hand or with help of a table in due form. (Anton, 2012)

4.6.10 Synergia

Ecological calculations tool called Synergia is an Excel tool to calculate the carbon footprint of the building materials. It is created by Ympäristökeskus, Finland's environmental administration. Synergia is widely used in Finland. For example in architectural competitions the environmental aspects are often defined with Synergia. For Synergia the building has to be massed in any design tool – which can also se a BIM software – floor by floor. The information is then exported into Excel, and further handled with Synergia. Synergia calculates the embodied carbon footprint by multiplying the masses of the used materials by corresponding ecological coefficient. Into these values the maintenance energy is included, but the manufacturing energy is not. The embodied carbon footprint calculation in Synergia takes into account also the maintenance intervals of the building parts. (Lylykangas, 2012)

Table 3: List over LCA or carbon footprint calculation tools which can import calculation data exported somehow, usually as a table in due form, from a BIM software.

Software	**Description**
Athena Ecocalculator	Table format calculator, results include embodied fossil energy use and several impact measures.
Athena Impact Estimator	Table format calculator, results include embodied fossil energy use and several impact measures.
BSLCA	A database solution to define environmental impacts of the building envelope and the building services systems.
€CO2 Wood House Calculator	A table format carbon footprint calculator for wooden structures, beta version available.
ENSLIC	Excel tool which calculates energy use and CO_2 equivalents from both operational energy and building material production.
e-Tool LCA	Measures the embodied and operational carbon, energy, cost and GHG emissions of buildings. At the moment it is not directy BIM compatible, but the commotion should be coming.
Gabi	One of the oldest LCA calculation tools available
Gaia Footprint	A service that provides information like carbon footprint calculations and LCA assessments.
IES-VE	Online software that creates building several types building analysis.
Ilmari	Online carbon footprint and LCA calculation tool with manual of Excel input.
SimaPro (CIRCE)	A tool to develop LCA studies of products, activities and services
Synergia	Excel tool for carbon footprint estimation.

4.7 Excluded calculation tools

There are several softwares that were left out from this survey. Many softwares seemed first as they would have been promising calculation tools, but in the narrow scope they do not fill the criteria. The excluded tools can be categorized to those carbon footprint programs that cannot be directly connected to any design program, those that calculate life cycle assessment, and those that are any kind of services instead of being a software. The softwares are in alphabetic order. They can also be found from the table 4.

4.7.1 Building Energy Evaluation by Graphisoft

Graphisoft's (2012; 2014) Building Energy Evaluation (earlier EcoDesigner) is fully BIM-integrated building energy modeling application for ArchiCAD. It is a BIM tool for the early architectural design stage. Energy Evaluation uses the same simulation kernel as the VIP Energy. Energy Evaluation as well as VIP Energy estimates the energy usage based on various variables as building geometry, climate data, heat storage mass and so on. But as the software does not create any LCA or embodied carbon footprint calculation, it is left out from this study.

4.7.2 DOE-2, VisualDOE and eQUEST

DOE-2 is a freeware that predicts the energy use and cost for buildings by using a description of the building layout, constructions, operating schedules, conditioning systems (lighting, HVAC, etc.) and utility rates provided by the user, along with weather data. The result is an hourly simulation of the building and an estimation of the utility bills. Software itself does not do neither carbon footprint calculation nor it is directly connected to CAD tools. The software is developed by James J. Hirsch & Associates in collaboration with Lawrence Berkeley National Laboratory (LBNL). The plain DOE-2 is quite complicated DOS software, but there are several implementations with graphical interface for easier use. (Hirsch, 2012)

eQUEST, the QUick Energy Simulation Tool, by Hirsch (2009), is a free Windows implementation of the DOE-2 program with added wizards. They guides the user through schematic design, design development and energy efficiency measure. The graphical results display module aids in the use of DOE-2. eQuest expands the DOE-2 capabilities in some ways. Third party developers can build additional certified tools into eQUEST. According Energy Design Resources (2012) there are 7000 copies downloaded, but the amount of active users is unknown.

Architectural Energy Corporation (2014) provides also a building energy simulation software called VisualDOE using the same DOE2 engine. It helps the user by writing the input file, running the simulation and extracting the results. It can be for example used for calculations for LEED certification. Still it does the same as the other DOE based softwares, which means there is not any embodied carbon footprint calculation.

4.7.3 EcoTect

EcoTect is a part of energy simulation programs by AutoDesk. It creates an energy analysis of the building, and it can be used in lightning design and acoustic analysis. There might be some bigger changes coming within AutoDesks programs, but at the moment there are not any features for carbon footprint calculation of materials and therefore EcoTect is excluded from this study. (Tuttujew, 2012)

4.7.4 ENERGY-10

Energy 10 is a gbXML (green building mark up language) utility developed by the National Renewable Energy Laboratory's (NREL) Center for Building and Thermal Systems. It can be used to analyze and manipulate energy aspects of the small buildings including the carbon footprint of the energy usage (Wong et al., 2011). It does not have functionality to calculate embodied carbon footprint.

4.7.5 EnergyPlus

To determinate and simulate energy and water consumption of the buildings there is a stand-alone simulation program named EnergyPlus. It is designed to help engineers, architects, and researchers to calculate the environmental impact of the buildings, but it does not calculate embodied carbon footprint and it does not communicate directly with any CAD program. (EERE, 2012b)

4.7.6 GaBi Built-It

GaBi has a special Build-It version of the GaBi software. With it, the building LCAs can be conducted following the German Council for Sustainable Construction (DGNB) certification variants. GaBi Built-It includes the maintenance cycles of the building materials, their end of life treatment and disposal as defined by the DGNB. The calculation is in line with the ISO 14040/14044 and the requirements of the DGNB. In addition to these, GaBi supports Environmental management systems ISO 14001 and EMAS. It gives the possibility to ecological comparison of different building alternatives within the planning stage, for the pre-certification and certification. GaBi Built-It includes also the comparison of different energy supply scenarios. GaBi Build-it includes over 600 eco-profiles for various materials and energy production. The information is fed manually into ready-to-use input area, which lead to exclusion from this study. GaBi Built-It is available only in German language. (PE International, 2012)

4.7.7 Green Building Studio

Green Building Studio is a web-based energy analysis software aimed for energy and thermal analysis, lighting and shading analysis, and value analyses. It is part of AutoDesk's EcoTect package, and it uses the DOE-2 simulation engine (Leinonen and Syvälahti, 2012). It can perform building analysis, optimize energy efficiency, and help to work toward carbon neutrality in the early design process. Green Building Studio is evaluated under ANSI/ASHRAE Standard 140–2004 (Standard method of test for the evaluation of building energy analysis computer programs) and certified by the U.S. Department of Energy (Autodesk, 2013). Green Building Studio can create geometrically accurate input files for EnergyPlus.

Today's building information modeling tools are not yet designed to accept gbXML input files which leads to problems because changes made in the energy estimation tool cannot be reimported into CAD-tool (gbXML.org, 2012). So at the moment changes made in Green Building Studio cannot be automatically incorporated back into the building information model. (gbXML.org, 2012; Autodesk, 2011, 2013)

4.7.8 IDA Indoor Climate and Energy

IDA ICE is a tool for dynamic simulation of indoor climate and energy calculation. It is a powerful tool, but does not calculate LCA or embodied carbon footprint. (EQUA Simulation AB, 2015)

4.7.9 KCL-ECO

KCL-ECO (VTT Technical Research Centre of Finland Ltd, 2012) is an LCA calculation program that can handle large systems and can define LCA for various products. KCL-ECO's features are: graphical user interface, impact assessment using different methods, sensitivity analysis, agglomeration function and graphic processing of results. According the manufacturer the audience is mainly industry, research institutes, universities and consultants, which shows that it is not aimed to help construction designers. KCL-ECO is an input output life cycle assessment software, but it is not maintained at the moment and it has no BIM integration which leads to that it is not handled more closely in this study.

VTT Technical Research Centre of Finland Ltd (2012) has created and maintained a related KCL-EcoData LCA database, which includes over 300 modules including LCA data related to various industries. It used to be commercially available, but has not been updated after 2008.

4.7.10 PHPP

The program called the Passive House Planning (Design) Package PHPP (Feist, 2007) is a calculation and design tool to help to optimize the passive house planning. The creators of the program have toiled to find out, which is the most important data for the energy usage calculation. Smaller expenditure on data acquisition reduces the possibility of the errors as simpler models are enough. This way the designers can concentrate on the most important variables. PHPP has been adjusted according ready built passive houses, but the results the software gives differs slightly from what is given in the European standard EN 832 (ISO 13790 – *Thermal performance of buildings. Calculation of energy use for heating*) as for some buildings the EN 832 turns out to be too optimistic. Unfortunately it calculates mainly the energy balance and does not tell anything about the carbon footprint of the building materials.

In the northern parallels of latitude, as in Finland, PHPP calculates as well very optimistic perquisite for the sun. It is not convenient for small buildings neither. During the interview Lylykangas (2012) reminded also that EcoDesigner (previous version of Building Energy Evaluation) add-on in ArchiCAD can export information directly into PHPP.

4.7.11 RIUSKA

RIUSKA is a DOE-2.1E based simulation software for condition and energy simulation. It calculates the technical behavior of the building and its inner areas under various load and weather conditions. It can be used to exchange IFC file between a CAD file and simulation engine. It is left out as it does not create any material based calculations, only thermal condition simulations. (Granlund Oy, 2012)

4.7.12 SolidWorks Sustainability

SolidWorks Sustainability is an LCA assessment calculation tool created by (Dassault Systèmes, SolidWorks Corp., 2009), and it works together with SolidWorks mechanical CAD program. SolidWorks Sustainability determines the environmental impact of product part or assemblies, but not for buildings. That is why it is left out from this study.

4.7.13 TRACE

Trane Air Conditioning Economics, or TRACE, helps HVAC professionals to optimize building's heating, ventilating, and air-conditioning systems. It also calculates load, system, energy and economic analysis. The program was first of its type when introduced in 1972 and became quickly an industry standard. But it does not calculate embodied carbon footprint. (Trane, 2012)

Table 4: List of various calculation tools that are for excluded from this study. They do not produce LCA is not separately mentioned.

Software	**Description**
ArchiCAD Energy Evaluation	Building energy usage evaluation, no LCA.
DOE-2	Predicts the energy use and cost for buildings, not CAD compatible.
EcoTect	EcoTect creates an energy analysis of the building.
Energy Plus	Calculates environmental impact of the building.
ENERGY-10	Analyze and manipulate energy aspects of the small buildings including the carbon footprint of the energy usage.
eQuest	A free Windows implementation of the DOE-2 program with added functionality.
GaBi Built-It	Building LCAs following the German Council for Sustainable Construction (DGNB) certification variants, manual input.
Green Building Stdio	Web-based energy analysis software aimed for energy and thermal analysis.
IDA Indoor Climate and Energy	Simulation of indoor climate and energy calculation.
KLC-ECO	Life cycle assessment software, not maintained and it has no BIM integration.
PHPP	Tool to optimize the passive house planning, calculates energy balance.
RIUSKA	IFC compatible tool, but calculates energy usage.
SolidWorks Sustainability	LCA calculator but for mechanical design.
TRACE	Optimize building's HVAC systems, no embodied carbon footprint calculation
VIP Energy	Energy usage simulation software
VisualDOE	Thermal condition simulations, no material based calculations.

4.7.14 VIP Energy

VIP Energy is a dynamic energy usage simulation software created by the Swedish company Structural Design Software in Europe AB (2012) aka Strusoft. It uses their own VIPCore Calculation Engine. The tool has been in practical use more than 15 years. Unfortunately it does not create any kind of embodied carbon footprint calculation and is therefore left out from the comparison. (Structural Design Software in Europe AB, 2012)

5 Interviews

To describe the current situation of embodied carbon footprint calculation in Finland specialist interviews were done. All together there were six interviews including totally eight experts. Some interviewees were found while screening the available calculation tools. The other ones were Snowball sampled, they were named during the discussions with people involved with BIM design. Both building designers – that most often create the model for the energy evaluations – and evaluation tool users are interviewed to get the overall picture of the situation.

5.1 Interview methods

The interviews are carried out using half structured interview method (Ruusuvuori et al., 2010). The used qualitative questionnaire gave quite open framework which allowed focused, conversational, two-way communication between the participants. The questions were the same (in Finnish) in all interviews, but the weight of the open questions changed from meeting to meeting. The questionnaire and it's English translation can be found from the Appendix A.

The one to two hours long interviews were conducted during the winter 2012–2013. The interviews focused on the following questions related to embodied carbon footprint calculation:

Which

1. tools,
2. data sources,
3. level of use,
4. purpose of use,
5. process stage of use,
6. user experience,
7. problems and
8. desires of improvements the users had.

In addition to full length interviews some less structured conversations took place during the period of the study. Many of these were email discussions when additional information about the softwares was gathered. Extra questions about more specific informations were addressed to professionals when required. All these contacts are referred according the nature of the contact.

5.2 Performed interviews

5.2.1 Kimmo Lylykangas

Architect SAFA Kimmo Lylykangas is well known specialist when it comes to timber architecture and sustainable design. Despite of having an own architectural office he teaches at Aalto University in the department of architecture. Lately he has participated in several ecological building projects and has been involved in academic research projects as well as cooperated with VTT Technical Research Centre of Finland. Lylykangas was interviewed due to his expertise in both architectural work and ecological aspects of buildings. The interview took place the 3rd of December 2012 in his own Lylykangas Architecture office in Helsinki.

Used software and databases

At Lylykangas's office they use for building design both AutoCAD Architectural desktop (ADT) and ArchiCAD. The quantities from for the calculations are taken from the BIM composite structures. Kimmo Lylykangas by himself has used excel based tool called Synergia for ecological calculations. It calculates the embodied carbon footprint by multiplying the masses of the used materials by corresponding ecological coefficient.

In Finland there do not exist any official database over the emissions. The opinions about suitable databases vary also between the experts. There is for example a good database called PAF, which is supported by some experts, but unfortunately all the information is gathered from the Central Europe. The origin of the material effects the ecological values of the materials, and in Central Europe the material transport distances diverge from what the they are in Finland. Lylykangas would like to see more local databases instead of loaned databases from far away.

The embodied carbon footprint calculation is conducted with the database included into Synergia software. At Lylykangas's office they do not perform the calculations by themselves, but send the quantity take of information further to specialists. For energy usage calculation the IFC models are sent to IDA Indoor Climate and Energy (IDA ICE) simulation software.

Carbon footprint calculation

In Lylykangas mind, it would be the most convenient to produce both the ecological calculations and the cost accounting from the very same model. This way the produced BIM information would bound these two important information types together. The information sources would be exactly the same, and while the cost accounting is anyway required, the material information could be available at the same. This would probably also diminish the temptation to take any shortcuts during the modeling.

If the customer gives any special requirements in the beginning of the design process, they usually just ask to reach the passive house level, or they ask the designers to suggest convenient level of the sustainability for the design. The embodied carbon footprint is not on the wish list as it is not anyhow official requirement. The calculations are mainly made only for for scientific or for marketing purposes. For example, for the Holiday Housing Fair 2012 (asuntomessut) in Lappeenranta the Lylykangas Architects calculated an ecological pass – including carbon footprint – for every house. Earlier they have won an architectural competition once as the design had a small embodied carbon footprint.

Lylykangas reminds that an important thing to remember is that the concept of carbon sink is not the same as the carbon footprint of the the material including the production emissions. It is also difficult to define any carbon footprint values for recycled material.

Official requirements

At the moment, without any official guidelines, it is difficult to say whether the embodied carbon footprint of the building is relatively good or not due to lack of official requirements, or even any common consensus over the calculation methods or system boundaries.

Lylykangas thinks the Finnish RT building information file could include product specific carbon footprint values. Also the sample composite structures included in the RT system could contain carbon footprint information. It would help if the database information could be fed already in to the design software; It would be right there where it would help the designer.

Defining the system boundaries causes problems. During the calculation it is quite essential to define the methods of the quantity take offs as clearly as possible. Whether the area of the building is the gross or the net area; are the wall area calculated along the inner or outer surface or maybe somewhere from the middle (the corners affect the calculation in differently in all situations). For some carbon footprint values both area and the volume can be used. There are also easier parts. The carbon footprint of the windows can be calculated very accurately by measuring the total length of the frames instead of just counting the windows itself.

It would be good if the details evolving in the building model during the design process could be taken into account as the design process goes further. Unfortunately the current technology do not allow this very fluently.

An open question is if the final sustainability values should be divided by the area or by the amount of the occupants. Also here the net area would measure the available living area, but the gross area on the other hand would be the same as what is required in the building permission, so it will be calculated anyway.

Remarks and suggestions for the future

When observing the whole design project, it would actually be good to be able to define the required carbon footprint levels instead of instructing specific material use. This type of functional sustainability calculation would secure always the best available solution as it would contain both material and energy usage and energy source information. This would create healthier competition composition regardless of the material.

The comparison calculations may give various differences between the material choices depending on how the comparison is done. The hardscapes of the building are one of the heaviest carbon footprint gluttons, and they are often very similar for any building structure type. So when comparing the wooden structures to other alternatives, actually only a small share of the carbon footprint comes from the carbon footprint of the wood.

For example in Heinola's wooden apartment house project the difference between wooden and concrete structure was quite small. If the comparison would be done systematically and the similar building structures would be left out, there would be more detailed information about the sustainability of the building and the real differences could be seen more easily.

The building plot affects also the calculations, but in Lylykangas's mind the building itself should not be punished by the site. On the wet land the hardscapes will have to be more robust. That kind of building cannot be directly compared with something built on a solid rock. Also, when comparing different options, the models should be comparable as well. This is actually one of the very basic problems with all reports, even those based on standards. The system boundaries should be the same. The construction site and construction work should not be included into the calculations.

The role of the designer is to carry out the ecological building design goals set by the customer. Some day the role could also include informing the customer.

5.2.2 Mika Leinonen and Roope Syvälahti

To gather information about CAD softwares, the AutoDesk distributor in Finland was contacted. Unfortunately their BIM expert had just left the company, but he was available for the interview via one of the Autodesk resellers called Cad-Quality Finland Oy, later Cad-Q. Mika Leinonen, Bc. Engineering, has been working with AutoCad and Revit all his twelve years career. Another BIM consultant, B.Eng in Design of Built Environment Roope Syvälahti was interviewed together with Mika Leinonen. Syvälahti has worked with several BIM software and works as a BIM consultant and trainer at the Cad-Q.

This interview helped to understand how Revit works as the writer of this study has better acquaintance with ArchiCAD. The interview was conducted in the 10th of December 2012 at the office of Cad-Q in Helsinki.

Used software and databases

Autodesk's main architectural solution is called Revit Building Design Suite Premium, shorter here just Revit. The light version of the software called Revit LT cannot be purchased with any add ons, which refers also to here later mentioned cloud service. In Revit, the construction type of the elements defines all the materials, colors and other details related into the building materials, including U value and maybe even the carbon dioxide emissions. In the near future the structure library will be extended and include physical, thermal and cost information as well.

An older software that still is good to mention in this context, as it is still widely used, is Autodesk Architectural Desktop, shorter just ADT. It is an architectural extension for basic AutoCAD software bringing 3D modeling and other specific features into the program.

Energy usage calculation tools for Revit are located in a cloud service called Green Building Studio. The cloud service is available for all customers with maintenance agreement. Maintained customers may conduct various ecological calculations whenever they wish to with the help of the service. The information can also be updated during the design process by sending the further developed information into the cloud. In the cloud the model could be altered, but the changes are not re-applicable back into the original model. It remained a little unclear whether the material information can be fed into the cloud as well. ADT is an older software and it cannot export gbXML format at all, and therefore it cannot produce convenient data for Green Building Studio either. Autodesk has also had an own environmental calculation tool called Autodesk Ecotect software, but it has not been updated since 2011. Both ADT and Revit are at least partly IFC compatible, but their energy model format, gbXML is not.

The quantity and cost information can be sent natively from Revit to Tocosoft accounting software, but there are also separate softwares like iLink for that purpose. At some stage Tocosoft will become IFC compatible as well, but it is not there yet. The IFC would make it better compatible with other IFC softwares as well.

Carbon footprint calculation

From Revit the building model information goes in gbXML format into Green Building Studio. According Leinonen it seems that the customers are more interested in Green Building calculation, which practically means the energy usage calculation for Revit. Carbon footprint calculation of the material is not at all as relish. Those, who need carbon footprint calculation, do it by themselves with other methods, not with the building design software.

Official requirements

During the interview any special comments about the official requirements for the carbon footprint calculation did not arise.

On the field of building energy usage calculation and energy sertificate Revit has some ready working methods. For the Finnish energy certificate all needed information has to be still hand picked. Other type of energy simulation is easy to conduct with a direct link into VIP Energy software. Revit has some local, Finnish modifications for the energy usage calculation, but it was unclear if they had some national data to be used as well.

Remarks and suggestions for the future

Revit has American origins. In USA the building design conventions are different from what they are in Europe or in Finland. Over there the technical engineer creates the energy model together with the MEP system model. This gives wider opportunities to modify the gbXML version of the building model.

Syvälahti believes that even the building designer could be able to add right material values into the model, especially if there would be ready, good and accurate data to work with. On the other hand the designer cannot always sure about the material finally used, so taking the trouble of defining the materials and values to exact might turn out unnecessary. Common, usable values would be good here.

5.2.3 Peter Anton

At the time of the interview Peter Anton worked as project manager at Vahanen Environment Oy, a large property management service provider with a wide range of multidisciplinary expertise. Earlier he has done carbon footprint calculations and worked as an environment consultant. At Vahanen Mr Anton is responsible for developing energy business and business models of buildings, industry, small scale energy generation and carbon footprint calculation. Earlier Anton has worked likewise with carbon footprint calculation and as an environment consultant. The interview took place the 11th of December 2012 at Vahanen's office in Espoo.

Used software and databases

Even though Anton himself does not create any kind of building design, he has a good picture about it as Vahanen has one of the Finland's biggest architecture offices as well. He has co-operated with architects in various projects. At Vahanen they use mainly Tekla for construction design, and ArchiCAD and Revit for architectural design.

Anton does not use CAD software by himself as he has worked more on the calculation side. He has user experience from two LCA calculation tools, GaBi 4 and SimaPro. From these two last mentioned, Anton finds GaBi heavy to use while SimaPro is more agile. SimaPro is more visual and faster than GaBi, but on the other hand it requires also less information for the calculation. GaBi does heavy duty work, but Anton admits he should use it more so that using the calculation software would be more fluent. According Anton SimaPro and GaBi use the same CML (The Institute of Environmental Sciences, an institute of the Faculty of Science of Leiden University in the Netherlands) information source as long as more detailed data is not available. For both softwares the information is fed by hand or with help of a table in due form.

GaBi has advanced solutions for car industry. At the moment the carbon footprint calculation of the car comes as fast as the quantity calculation. Probably it is easier to dismantle a car into clear separate parts, and the volumes of similar parts are so large that there has been a point in devoting effort on calculation development. GaBi's representatives had said the same would be possible for buildings as well, but the price range of the solution was out of question for the company back then.

Apart from those softwares Anton also knows Synergia, a table calculation system that is used in Finland. In some plot reserve competitions Synergia is the definite method to create the calculation so that the results would be somehow comparable. Still it leaves the freedom for the calculator to choose what to feed in and what to leave out. It is good enough especially for small projects to calculate the comparison numbers when the absolute environmental numbers are not required. In this context small project refers to MEP renovation and large project to the whole building, for example.

Carbon footprint calculation

The quantity take offs about the building (of other product) come from the customer. The normal procedure is that the environmental calculations as well as later the construction plans are created based on the architectural BIM data. The tenders are given based on the construction plans.

In the best situation the calculation experts have the access to the project in very early phase so that they can propose solutions to improve the design into more ecological direction. Unfortunately this is rare and usually when the calculation experts come into the picture, the possibilities to affect the design are already limited.

At Vahanen the carbon footprint calculations are sold as separate projects. Very few customers ask for them without a specific reason, but the possibility to make them has to exist. The ones that are interested in the calculations are the owners of the buildings, not the constructors.

Some architectural competitions have ecological effectiveness as one criteria. Most often only the changes made to decrease the environmental load are taken into account and therefore the shown change is calculated. Otherwise using time and money on any extra calculations is very rare. And this applies to architectural offices as well. Even if the environmental awareness is one of the office's principal themes, the calculations are done only when needed. Which is usually for competitions.

In some cases the constructor or supplier may give a proposal for an improvement to the design or material choices that might affect the ecological values, but usually the calculations still remain as they were. Of course the calculations could be updated according the realization, but this is done very seldom. The emission differences between the materials are small and the quantities should be huge for them to affect the final result.

Gathering the information for the calculation is burdensome phase. Often the required information is unavailable or it does not even exist so that it has to be replaced with approximations. In 50 per cent of the cases the information about the material specific carbon footprint emissions for the calculation come directly from the manufacturers. In the rest of the cases Vahanen uses usually GaBi's database, or some other resource that the best corresponds the required value. Large Finnish manufacturers have the best availability of the values. It is more difficult to receive any information from smaller companies and abroad.

Official requirements

Right now the greatest hype about carbon footprint has dropped from what it was at some stage. In the beginning of the 21st century there was a long list of environmental declarations in the Finnish building information file, but now there are just a few. The declarations are valid only for five years and it seems that the companies have not seen reason to update the data. Does this mean, that the subject of embodied material emissions was interesting ten years ago, but now the attention has moved to the used energy instead? Environmental product declaration EPD will be required in the near future, maybe this will push the companies again.

Remarks and suggestions for the future

One of the biggest problems is the framing of the calculation; what should exactly be taken into account. There are several standards, even very exact ones, that defines the basic calculation method. But there are always possibilities for exceptions which just has to be explained in the report. Which again make the exact method unreliable without reading the full report and all the existing exceptions. The report does not give straight comparable information, at least not without heavy through reading. Maybe, if the calculation methods would be simplified in the same way as the energy usage calculation of the buildings, the results would become directly comparable. That would require an easy tool with clearly defined information input.

In Anton's mind the building designer could create additional value for the design by developing his or her own knowledge about ecological building and its methods.

In general extrapolating one building material to be better that the others would be wrong. Benevolence of any method depends on the case on hand every time. Once, for example, a wooden structure for a bridge in Espoo ended up being the most problematic regarding carbon footprint while the two other alternatives, steal and concrete had about similar results. In that case the customer was free to choose between the two last alternatives.

Anton believes that the energy usage of the building during the usage phase in Finland is at least 95 per cent of the total energy usage. Somewhere given 80 per cent might the total average in several countries, including many warmer that what Finland is.

5.2.4 Tuovi Valtonen

As a specialist about ecological material information a LCA research scientist, Tuovi Valtonen from Stora Enso Renewable Packaging, R&D Services, Research Centre Imatra was interviewed. She carries out various life cycle calculations, factory declarations and environment certifications regarding wooden structures, wood components, paper and cardboard for Stora Enso Timber.

Mrs Valtonen's area does not actually belong to the subject of this study, but the information about how to produce ecological data of the materials was very useful in understanding the background system. Due to the distance the interview was carried out with an internet call software 12th of December 2012.

Used software and databases

At work Valtonen uses KCL Eco software, which is a modular process description and calculation software. The process modules can be built by the user, or in some cases ready existing modules can be used. In practice at Stora Enso they create the desired process simulation, connect the process flows and verify the material balance in the system.

Together with KCL Eco came a database called EkoData, but unfortunately VTT Technical Research Centre of Finland does not maintain it anymore. In Stora Enso they mainly use primary data to calculate the carbon footprint instead of database information, which is more accurate. The databases are broad estimation about the reality, and using them is arguable, says Valtonen.

Carbon footprint calculation

Due to customer demand the fossil carbon footprint calculation by Stora Enso is done "cradle to gate". Some customers are happy with plain results and numbers, while the others ask for detailed information which they use then in their own calculations.

CePi (Confederation of European Paper Industries) has created an own, *ten toe system* to build the carbon footprint of printed paper. Every one of the toes consists of one part of the production; carbon dioxide bound into the forest, carbon dioxide bound into the printed product, carbon footprint of the transportation etc. In paper industry it is also important to reduce the production energy. There are not any official requirements for carbon footprint of the products, but in some countries the public sector takes decisions based on CO_2 values. In some cases the customer wants to indicate the environmental state of the products as a marketing extra. In these cases it is a bonus both for the seller as for the buyer to be able to show the ecological numbers of the products.

Official requirements

According Valtonen's words, on the construction side the standards have more power. The new EN 15804 defines environmental product declarations. The EPD is under evaluation and probably it will be confirmed 2014, and after that it will be taken into use. There will also be an own standard especially for wooden components.

Remarks and suggestions for the future

Products could have their own modules, a unit which respond for a specific CO_2 (or other indicator) value. The downside of this approach would be that for example for fine paper one module would be far too wide concept; the real carbon footprint could be only half of the table value, or double. There are several reasons for this. The emission information outdates, and for example for the electricity the emission factor varies depending on many factors like differences between countries, contract of purchase, mean emission calculation requirements (in EU for example) and database information.

Valtonen suspects that every industry has problems with disunited modus operandi. In her mind it is good that the standards are created, by existing they would create pressure to take them into use. The designers should get mentally ready to provide for the new requirements.

5.2.5 Erja Reinikainen and Robert McGrath

One of the very skilled energy consumption and environmental impact expert interviewed was Erja Reinikainen from Granlund Oy. After her graduation as a Master of Science in 1980 she has been working with dozens of projects related to energy consumption and environmental impacts during the life cycle of buildings. Together with Mrs. Reinikainen, another expert, sustainability consultant Robert McGrath represented Granlund Oy. In the past he has worked at Kimmo Lylykangas Architects as well. This interview handled mainly about the progress of LCA calculation in Finland and what requirements the LCA or carbon footprint calculation sets for the architectural design. The Granlund stuff works as consultants and calculators when it comes to environmental evaluations. The interview took place the 18th of December 2012 at Granlund's office in Helsinki.

Used software and databases

Granlund had earlier an own BSLCA software for calculating the carbon footprint, but the software development was discontinued. The objective of that project was to create a model for building services software development and information management based on interoperability and open data transfer. In the end the problem was that the IFC BS(L) Pro interface would have needed an update, which never came out. BSLCA is based on the model and it was aimed to the export markets. The IFC data transfer format was applied and know-how related to IFC technology was advanced in the project. The project covered the entire building services implementation process and included new software tools. In the BSLCA there was various ways to categorize the data. The coefficient of the data could be changed or alternated depending on the calculation method. DAIA (Decision Analysis Impact Assessment) method is one of the characterization and valuation methods implemented in the BSLCA tool.

At Granlund they also use RIUSKA, which is a dynamic energy simulation software, and Synergia, which is a very fast and lightweight solution. It takes about one or one and a half day to calculate the CO_2 emission for a project.

BREEAM (BRE (Building Research Establishment in UK) Environmental Assessment Method) is a voluntary building rating system, which is also used at Granlund. In BREEAM decisions are based into alternative choices. It has the idea that it should be shown that there have been different alternatives and then the most ecological and convenient one is chosen. BREEAM could not be used in BSLCA.

The databases they use at Granlund's are not Finnish, the data has international origin. For example the BREEAM uses German data, actually GaBi.

Carbon footprint calculation

The best phase to do the environmental calculations would be the building design creation phase, or in the very beginning of the project. It is then when making changes into the plans is very easy. The work flow is following: First architect creates the building design, and after that a separate designer creates the structural design. Then the HVAC system is applied to the building, and at last step is to check the goals.

Often the calculation services are bought from specialized companies. The designers themselves are not interested or they do not have the skills to conduct the calculations. In the most large projects the energy consultant is part of the design team. The energy consultant should keep the team informed about the environmental aspects of the design.

Reinikainen and McGrath believe that the role of the consultant will become more clear as the environmental requirements for the building increase.

The quantity take offs from the architectural CAD software can be used in the calculations, but they are not really of good quality. Usually at Granlund they take the geometry and the areas from the architect model, and then define by themselves other structures like doors and windows. Neither do the architects create the model correctly for various energy calculations. They model the elements and there is just empty space in between the elements. In energy calculation the energy demand is calculated based on the energy required by that empty space. Some modern CAD software can take this difference into account, but the working methods change slowly. At Granlund they have not tried to import a modern CAD model directly into the calculation software. The designer could ask help from a specialist, but there is seldom time or special opportunity to improve working methods in the middle of the project.

In the design phase the material sources are yet unknown and the designer can not say where the final construction materials comes from. So, the materials have to be assumed in the early phase. At the same time, the design model is not identical with the as build model. So actually, the building should be separately remodeled after the building phase. This is not done in current situation.

Official requirements

When exporting goods into different countries it has to be kept in mind that the legislation varies depending on the destination country. In this context the standards help to harmonize. Environmental declaration is a new standard (EN 15804), but even that new standard leaves loads of discretion. According Reinikainen and McGrath the calculation itself is easy as soon as the information is available.

Usually the energy calculation is ordered by the constructor or by the owner of the building. In Finland this kind of instances are Senaatti properties and Sponda (real estate investment companies), HUS and other hospital districts, cities, insurance companies and other large companies like Kesko (a Finnish retailing conglomerate). Mainly the calculations are about commercial and public buildings.

In Finland the preliminary calculations are rarely done, not even for BREEAM that would actually require them. Due to old working methods there are not enough source information for the calculations. Gathering all that information would mean extra work, and it is therefore left out. The investments does not either include margin for new uncommon experiments like extra calculations that are not officially required. McGrath and Reinikainen both think that Finnish operational environment is not ready to devote resources for ecological values. Restricted financial assets do not give chances to work differently.

Some kind of environmental LCA tax might guide to favor environmental design. In Australia there is already a cost of carbon footprint defined as by the price per CO_2 ton.

One more thing that makes it less interesting to calculate the material carbon footprint is that only one to two per cent of the total energy consumed by the building during its total life cycle comes from the end of life information. Due to the scale, it is not usually added into the life cycle calculations. During the discussion the energy usage for 50 years life cycle of the building was mentioned to be about 80 to 85 per cent, but again, the interviewees admitted that the information is about 10 years old. What are the new values?

Remarks and suggestions for the future

The customers should understand to require right things, official or not. Are they paying only for doing the job, or also for developing the design methods and results so that they will some day fulfill any additional requirements as well? And should the responsibility of developing the methods be at the customer's or at the designer's side? Real estate investment activities, construction sector and design culture are in transformation phase and despite of all the current problems, the design culture and conventions change. There will eventually born new ways to act. The role of the architects will change anyway in the near future. It depends a little, how much they are interested in more ecological design. The architects and other building designers cannot define the final quantities, but they could do their best with all available information.

One answer to the calculation model would be a simplified calculation system, for example with steps, something like Green Guide A, B, C in England. The simplified system would be easy to access for the designers. The environmental aspects would be taken into account much more than before even though the calculation system would be simplified. Good example of this was already the energy usage calculations, which became obligatory in Finland 2008.

5.2.6 Matti Kuittinen

Architect and researcher Matti Kuittinen works at Aalto University and has also acted as the leader of the ECO2 project. As his own business Kuittinen runs an architecture office that concentrates on small scale buildings like single family and row houses. The office has expertice on environmental friendly house design. In addition to these Kuittinen participates also to humanitarian aid design projects. Matti Kuittinen was interviewed 11th of February 2013 at the Department of the Forest Products Technology in Otaniemi, Espoo.

Used software and databases

Kuittinen creates the building designs with ArchiCAD START Edition (SE), which is a light version of the full ArchiCAD.

Excel and Synergia are used to conduct some elementary environmental calculations. For more detailed information extra calculations are ordered from specialists that use particular LCA softwares. Also Ilmari, the software VTT has been working with, has been tested, but there are is still some development to be done before it can be used in larger scale.

The VTT's own, large material database is often used for the calculations. IDA ICE does have a good, comprehensive database. It is free, but it does not include for example carbon information of wooden products or other biological or fossil tables. In March 2013 there will be an open database of European products.

Carbon footprint calculation

Kuittinen estimates that roughly one third of the customers are interested in the carbon footprint of the buildings. It is common that they do not actually know what they want and the architect can make suggestions to help with the decisions. Sometimes house manufacturers ask for bills of quantities of the buildings, but that is usually all. Architect is paid to create the design, not to do anything else. The MEP designer (mechanical, electrical and plumbing) will take some additional quantity take offs for more detailed design and calculations from the architectural model.

The main purpose of any calculations that are created based on the model are for official energy certificates. Most other calculations are created for scientific purposes. Depending of the needed information, the calculations can be done for example with Synergia. For real life any additional calculations are still too heavy to be conducted without special need.

One point that came up during the interview was the question how IFC can be used when it comes to embodied carbon footprint calculation. Some modifiable IFC parameters can be used to carry element specific information, but is it possible to connect the information with materials? By this far it seems to be so, but the question remained unanswered.

Official requirements

The new European construction products regulations brings the EPDs into use. They will be one of the methods that would guarantee the product the sufficient amount of information for the international European market.

Kuittinen believes that most of the EPD's are now expired because there has not been any official requirement for them. The new European construction products regulations will come into affect the first of July 2013. It will be then when the CE mark for products will be mandatory. This brings the official product information into comparable form, and using products in foreign countries will be easier.

Remarks and suggestions for the future

The technology could help the designer to take the decisions. For example it is known that the calculations based on an architectural model do result differently from calculations conducted later. It is an important question if the designer ever has enough information for all environmental calculations. It is often first in the construction design phase when some more detailed information is available. Some simple guidelines would be useful. Estimates of the differences would help the architectural designer to verify whether the design it going to be very successful, or should some additional fine tuning regarding environmental aspect be done.

Kuittinen thinks that in the future the supervision should be directed into more area specific direction instead of comparing directly alternative materials unlinked to the building location. This would mean that instead of studying the building plan out of it's context, the plan should be placed into it's real environment. It would be much more convenient to compare different options by connecting the building into it's future building site and see how well it fulfills the requirements there, with all material choices. Different materials are suitable for different uses. Also the purpose of use has to be taken into account. It has significant importance whether the building is for occasionally use – as a summer cottage – or for heavy duty, high requirements construction – as a central hospital. The meaning of the material choices is in totally different level.

5.3 Summary of the interviews

The interviews were performed during quite short period. The area of expertise between the interviewees varied. For some reason, only companies that were interested in ecological design in general had time to participate. Normal architect offices contacted declined referring to rush at work. So, the answers are weighted on more environmental aware professionals. It would have been ideal to reach a normal designer as well, but it was not possible within the reserwed time.

Kimmo Lylykangas and Matti Kuittinen are architects and they has the best touch into the practical design problems. Also Roope Syvälahti and Mika Leinonen belong into designer group as they are both construction architects and they have track record of house design. Their speciality is more in the CAD software knowledge no-one else of the interviewees actually had more deep experience in that.

Peter Anton, Erja Reinikainen and Robert McGrath were representatives of the instances that actually provide the calculation service. They knew what kind of information the average designers hand over and what is the quality of that information. They could also point out the flaws in the architectural models and give quite detailed information of calculation softwares and databases. Robert McGrath is also an architect and has worked earlier for Lylykangas, so he could merge the design knowledge into environmental evaluation requirements.

Tuovi Valtonen was the only professional that did not have directly anything to do with building design and environmental calculation of whole buildings. But she could describe the problems and methods of creating the databases; what everything should be taken into account and what problems there will always exist even after careful examination of materials.

6 Results

In this chapter the results of the study are presented. First there are the results from the interviews and later overall results divided into sections according to the research questions. The goal of this study was to report the current situation of the frequency of carbon footprint calculation especially in the early stage of the building design.

In the first section, the results of the interviews are examined. In the second section, the gathered information about the softwares is presented. The third section presents conclusions of the two previous sections.

6.1 Comparison of viewpoints of the interviewees

In this study the information of the current situation of carbon footprint calculation based on building information model (BIM) was gathered with interviews. The following chapters precis the viewpoints from the interviews.

6.1.1 Used softwares and databases

In Finland the most used softwares in the architectural design of buildings are Revit and ArchiCAD. They are both modern, IFC compatible 3D design softwares and fulfill most of the requirements designers and regulations set to this kind of software at the moment. Older versions of various softwares are used as well, but unfortunately they lack many modern interoperability features. ADT (Autocad Architectural Desktop) is used by some offices, but as it is not fully IFC compatible and it cannot export information even to Autodesk's own Green Building Studio cloud service, it was excluded.

None of the interviewed architects used more advanced carbon footprint or LCA calculation tool. When more detailed environmental information is needed, they consult specialists who use particular calculation software. Several calculation softwares were mentioned during the interviews, but they did not fulfills all criteria set for a calculation software in this study.

The best integration between the BIM and carbon footprint calculation software seems be the possibility to move information from Revit further into the cloud calculation service, Green Building Studio. But that is not a fully integrated, two way evaluation system as the information cannot be moved back to the modeling software. Green Building Studio is not IFC compatible. SimaPro is a large expert tool that is not meant for every building designer. In Peter Anton's (2012) mind it is more agile and visual than GaBi even though is uses mainly the same database. On the other hand it requires less information than GaBi. However neither of them is IFC compatible, so they are both excluded from list of accepted calculation softwares of this study. GaBi could be altered to produce carbon footprint calculation automatically, but this customization would be expensive. Building industry is an old-fashioned sector and there is no active demand for the calculation, so it has not been done. RIUSKA is a Finnish environmental simulation tool. Unfortunately it does not create any material based calculations, only thermal condition simulations. Synergia was mentioned many times, but it does not fulfill the calculation tool requirements of this study at all, as it is only an excel table which works as a calculation help. Synergia is not IFC compatible. The positive side with Synergia is that is has somehow established status in the Finnish architecture design and architectural competition field. This makes the calculation methods quite comparable. But the selective manual input method provides for the person responsible for the calculation a possibility to leave out some detail of information and this way get lower CO_2 results for the design. Still, it seems to be a good tool especially for small projects and when precise environmental numbers are not required. During the interviews also many other softwares were mentioned, but they were dropped out for different reasons. Valtonen from Stora Enso was the only one to use KCL Eco tool together with EcoData database. It is meant for more detailed chemical LCA calculation and therefore not handled here. VTT has a new software called Ilmari, but it is still in beta phase. According to the tests done so far the biggest shortage is the inability to export building information model directly in to the software. On the other hand one direction excel form input is a fairly good base for further development. It should not be difficult to create a direct connection between an IFC and a calculation software.

In addition to particular software there are the building evaluation systems, such as BREEAM that should help with ecological calculations in the early phase of the building process. But in Finland the working methods and source information do not support this approach. Granlund's own BSLCA might have been a promising carbon footprint calculation tool, but the software development was discontinued due to lack of interface update not depending on Granlund.

One of the biggest problems at the moment seems to be the lack of usable databases for calculation. No good quality, widely used Finnish database exists that would include real or even approximative values to express carbon footprint of the materials in Finnish environment. Most of the databases are European and they come along with large calculation softwares. Creating usable databases for the construction branch is difficult. The same product can be produced much more ecologically by using recycled material and renewable energy sources. Still, in the database the material may probably have only one value that is used by the designers. This one value can give too positive or negative image of the material. In the latter case an effort made to create more ecologically friendly materials will loose some power, only due to an average database.

IDA ICE is a much used indoor climate and energy evaluation software and it is delivered with a comprehensive database. The only thing is, that it does not include for example carbon information about biological or fossil materials. KCL Eco used EkoData database byt VTT, but it is not available anymore. VTT has its own database, which is new and accurate in Finland, but it has not yet been taken into use elsewhere. GaBi is widely used and one of the oldest LCA softwares for LCA calculation. It also has a large martial database. Many commercial companies providing environmental calculation services seem to use GaBi.

There seems to be variation between the interviewees' opinions regarding what would be a good form of a database. While handling the main question of a good database, the purpose of the usage of the information should be defined as well. With many interviewees the discussion ended up with the question of how to create accurate material or product information. The fact that in the very beginning of the design process the model is anyway suggestive and cannot be used to calculate any exact environmental values. This leads to a thought that in addition to an exact database with product mark specific information there should be a database with more common values to be used in Finland. Lylykangas underlines separately the need of local data. Estimations from far away are not accurate in any way. It has to be kept in mind that calculating carbon footprint for a building in the early design phase does need database level information about common building materials. In comparison for example specific products do need exact environmental load. The databases are far too broad estimations for product information calculation.

Gathering correct information for the calculation is a burdensome phase. If the calculation is done in the early phase, the exact information will have to be replaced with approximations. If a manufacturer wants to promote its own, distinctly different or better solution in the database, it should be quite easy to insert more accurate information of the products. As long as the need is more for a comparison information between different material and construction choices, a more common database might work better. For the designer it is not that necessary to get the exactly right information, but to be able to estimate the results and therefore to pic up right material and design choices.

6.1.2 Carbon footprint calculation

According to all interviewees separate carbon footprint calculations are rarely done. This fact stepped out in every interview, but because it is not officially required and it does not add value so much that it would be worth of creating. The Finnish operational environment is not ready to devote resources for ecological values. Restricted financial assets do not give chances to work differently. Most often the calculations are created only for scientific use, sometimes for architectural competitions. Perhaps it becomes a competitive advantage in the future while ecologic awareness grows, but it is not seen as one at the moment.

It seems to be a well known fact that an architectural model is not made to be used for more detailed evaluations. As the architectural model is not accurate enough for the environmental calculations, the calculation professionals often remodel the entire building just for this purpose. This type of data handling – remodeling the buildings – means a higher possibility of the errors because of the human intervention. Syvälahti believes that building designers could learn to create right type of models. They would just need good instructions and much better material information data for that.

If some calculations are needed, they are ordered from specialists as the architects cannot create the more advanced calculations by themselves. At the moment the architects get paid for creating the design, not for making additional calculations. Only in the largest projects energy consultant may be a member of the design team. MEP designers and other specialists do more that type of work this study is looking for.

In the USA the building designer usually creates a wider design plan, including MEP design for example, than what the Finnish architects usually create. This gives them better opportunity to think of the building as an entity and make better ecological decisions. Even though we would not copy the same system to Finland, the architects could learn about the way of thinking a bit wider than only their own "task".

So far the possible carbon footprint calculations are usually conducted based on the quantity calculation of the building model. As long as the building is correctly modeled, the results give good estimates. Good thing about this method is that the cost estimation – in that form it is done today – can easily be bound to the environmental information. Once the quantities are listed, all calculations can be based on the same information. This would probably also diminish the temptation to take any shortcuts during the modeling. The downside of this method is that at the moment the data transfer from the BIM software into the calculation tool requires manual intervention and any possible updates mean more work. This method is too heavy to be conducted with every project. Also the quality of architectural work is not good enough for exact detailed calculation. Maybe, if the calculation would be more standardized, we could reach more effective workflow and find advantages.

Another aspect is the level of details in the model. The entire building can be modeled geometrically exactly as it will be built, but without material information. This can be done with a BIM software, but naturally it is not BIM as it lacks the (material) information. It is possible to create quantity calculations based on the wall volumes and then use multipliers in order to get calculation results. However, this type of modeling does not fulfill the modern BIM and IFC requirements and should not be used.

Lylykangas misses real system boundary definitions and common play rules to the calculations. Also the fact that in the beginning the model is quite simplified, but it usually gets more details as the project advances, should be remembered when making the calculations. This could be one feature that the new calculation tools should take into account, and redefine the values again with the more exact information.

The best phase to create the calculation would be in the very beginning of the building design process, when making changes is still easy. At this phase the experts could suggest changes to the model. If carbon footprint calculation is conducted, it is done in a quite late phase of the project and preliminary calculations are rarely done. One reason is that there is not enough source information for the calculations, which makes it even more rare. On the other hand, the architects should learn to think environmentally and take the carbon footprint aspects into account in their work. This means, that no exact material information is needed either. Common values depending on the structure and overall material choices are more important.The emissions calculation may change and become more detailed during the project, but usually the calculation is done only once.

The paper industry's ten toe system, which Valtonen described, could also give some advise about the possible calculation method. Dividing buildings into sections, each section could be examined separately. For example the hard scape structures are not directly dependent on the material choices of the rest of the building and therefore they could be calculated as a separate section. This would make it also easier to compare different building structures.

6.1.3 Official requirements

The building construction types have changed during the years and the official requirements are more strict than before. Therefore the old design and building working methods might not work anymore. Before any changes into the approach of the requirements is done, it would be good to define the concept of accurate building information model. Is BIM a model optimized for calculations, or does it answer the demand of the needs of the old routines? Ideologically they – the two versions of the BIM – are the same, but there is a difference between the theory and real life. Taking the design phase (called L1-model in Finland) into account when defining the needs, also the already-required E-calculation will become easier.

There are some possibilities to develop the situation so that the knowledge about building modeling would spread.

- To design a product neutral or specific product conscious sample house together with a party that can then further distribute the knowledge of the structure choices and model information. This kind of instances could be (in Finland) Finnish House Owners Association or Puuinfo, a Finnish Wooden Architecture and Wooden Construction society.

- To search for a ready house model to be edited. Some calculations could be done directly from the architect model, but the model would be edited so that it would become more correct in relation to the environmental calculations. The comparison would give feedback from the differences between the design habits and needed information. At the same time some design guidelines could be created.

- A company, that works with building information modeling, could create this kind of model by themselves and distribute the information.

Among the interviewed professionals it seems that all of them wait for the new regulations to make the environmental evaluations more common and better structured. Before that, only large companies, that can afford to invest on environmental perspectives, will ask for them. A European standard would also unify the legislation at least in European countries. So far the requirements have been different and exporting goods as well as creating the calculations has been difficult. Lylykangas reminds, that comparing building alternatives is easier, but at the moment there is not any official way to tell whether a design is relatively good or not. The official, or even a common, consensus over the calculation methods or system boundaries is missing. Valtonen commented that on the construction side the standards have more power that on the product side.

The new Environmental construction product declarations EN 15804 + A1:en came into affect in the 2014, which Kuittinen thought would probably boost the registration of Finnish building products. Some building components will get their own standards as well. Many of the interviewees explicitly expressed that the EPDs could be a good source of information for a database, if they would become obligatory. Although even this new standard leaves space for discretion.

The Finnish RT Building Information File could also include carbon footprint values. Now they are not included if the product does not have the full EPD. The interest towards the carbon footprint has abated and many of those EPDs that once existed, have expired. Without official pressure the companies have not found a reason to update the EPDs. At the time of the interviews, the EPD's in the Finnish RT Building Information File were expiring.

One way to speed up the development of the calculation methods would be to add environmental LCA tax. Reinikainen recalls, that it has helped the situation at least in Australia.

The question about what else should be taken into account when creating the environmental calculations churned also in the interviews. The comparison between building materials is one of the factors which will probably become easier as the rules for calculations become more clear. Another interesting point of view regarding the official requirements is whether the requirements for different projects should be different. The building site and the purpose of use do affect the construction and material choices and therefore in some cases the most ecological method is not an option. This leads to that all buildings cannot be measured with the same criteria.

6.1.4 Interviewees' suggestions for the future

Rising the awareness of the environmental question seems to be one of the keys to advance with CO_2 calculation. Real estate investment activities, construction sector and design culture are in transformation phase and despite all the current problems, the design culture and conventions change. New ways will eventually born.

Some simplified solution for the LCA calculation could be the first step when connecting the calculations into the real life routines. The British ABC method or paper industry's ten toes system could work as examples. Or product specific units that would stand for specific CO_2 values. Any common method would also help to define the calculation framing in the future. The first common calculation methods might not be as exact as the deeper methods at the moment, but even a simple method would unify the routines on the branch. By creating standards also the pressure to take them into use will rise.

A simplified method would also be a step towards better outlining of the calculation. At the moment it is not always clear, what is included within the calculation result. The current reports do not give straight comparable information. When comparing different options, the models should be comparable as well. This is actually one of the very basic problems with all reports, even those based on standards. The construction site and construction work should not be included in the calculations when the aim is to compare the environmental values of the materials.

Kuittinen reminds that the building designer probably never has enough information to make detailed environmental calculations. Easy estimation methods would help the architectural designer to verify whether the design it going to be very successful, or should some additional fine tuning regarding environmental aspect be done. Designer cannot be sure about the final material choices either, so a database about consultative values would be very useful.

Granlund's and Vahanen's representatives remind that even though the architects and other building designers cannot define the final quantities, they could do their best with all available information. As Lylykangas put it, the role of a designer is to carry out the ecological building design goals set by the customer. But the customer will probably not ask for much more than the official requirement defines. It is up to the designers, how much they are willing to increase their knowledge about ecological building.

Carbon footprint of the building materials stands only for 1–2% of the total lifecycle of the building, but as the building technology develops all the time more energy efficient, the day will come when the materials will play a bigger part in the picture.

6.2 Calculation methods at the moment

The research showed that in theory there is a standardized way to conduct the calculation, but the work is burdensome. The softwares do not support the information exchange and a lot of work has to be done manually. This rises the chance for mistakes and gives a chance to misinterpretation which reduces the credibility in the results.

To help with the work of ecological calculations the architects could produce quantity calculation data based on the 3D model they anyway create of the building. However, there seems to be a few problems with this. One is the fact, that without good guidelines the architects cannot produce the right type of model for the calculators. The architects do not have the convention of taking the further usage of the building model into account. The traditional architect model concentrates on visualization of the construction parts like walls and slabs, and the information bound into the elements is misleading or totally missing. So the sustainable design consultant cannot use the model the architect has created directly, but he or she has to remodel it. This happens partly due to modeling practice, lack of knowledge and poor instructions. 3D modeling is still a relatively new manner of representation compared to drawn plans. While BIM gets more common, also the designers should learn to use it correctly.

The calculation accuracy in different phases of the building project can be discussed. The standards mentioned in chapter 3.2 mentioned standards (for example EN 15978, Sustainability of construction works – Assessment of environmental performance of buildings) are created for the final calculation. They have not been created to be used as design guiding tools to generate more ecological design, but to prove the ecological position of the ready building. This approach is much more accurate and exact than what is actually necessary in the early design phase of the building design.

As it arose during the interviews, easy calculation methods are needed. Something similar as E-value calculation for the energy usage of the buildings, or ten toe system of the paper industry, would help to get started with the more common carbon footprint calculation.

6.3 Current calculation tools

Several software manufacturers have created their own design assistant tools that in a way or another help the architects to make energy efficient and ecological decisions. But the use of that kind of tools is yet quite slender. The tools can give an estimate about performance of some ecological sectors of the building, but not the final and the most exact numbers required for example in standards. And very often they concentrate on calculating energy usage, not material information. Use of these softwares is still very well justified based on the fact that the design decisions made in the early design phase affect in 80% of the final results. Very often these softwares are totally or to a high grade integrated into CAD programs for which they can only be used with models created or imported into that specific CAD tool. The recalculation can be done very fast after any change in the design and the affect of the change is easy to see. The downside of these tools is the shortage in the database information, which makes the result mainly comparable within the results received from the same software. Also most of the calculation softwares meant to be used in the early design phase, as EcoDesigner or Green Building Studio, calculate an estimate for the energy usage instead of embodied carbon footprint. In addition, today's BIM softwares are not yet designed to accept gbXML input files which leads to problems when changes made in the energy estimation tool cannot be reimported into CAD-tool. gbXML seems to become a common format, but at the moment it is not IFC compatible.

In Finland there is now a growing demand for tools to create the calculations as the requirements change little by little. Puuinfo has created a simplified E-factor calculation tool to help the designers. It is only an excel based table for the E-factor estimation, which has become obligatory in Finland in 2012. But yet, and maybe therefore, the tool has been well received by the building designers.

There are also several softwares that can be used to calculate the final carbon footprint of the building. They are taken into use in a very late phase of the design, or after the whole design and maybe even the building process is ready. The material ecology calculation tools are for specialist use only.

At the same time most of the calculation programs intake only manual input, or there should be data table in a certain format to be imported. There is an acute need for solutions, but finding the consensus is not easy. The modern directly linked methods to conduct the evaluations are the most effective and accurate. It can be seen that the software houses have not yet made building designer level products for this.

The research showed that there is certainly shortage for low entrance level tools for carbon footprint calculation with close integration to design and decision making. It is true that the meaning of the embodied carbon footprint of the building is small compared to the energy used of the building during whole lifecycle. But as the operational energy usage decreases, the proportional significance of the other parts of the construction lifecycle grows.

One more problem is that even though the design softwares are already very advanced by their features, they still do not interact with calculation tools. Or the calculation tools do not interact with BIM software. There are several examples about this. Reinikainen (2012) told they had been developing LCA calculator that was compatible with CAD programs already in the beginning of 21st century. They believed, that the ecological mindset would soon gain ground and that there would be growing demand for such tool. But this did not happen and it took ten years before even the energy calculation was a decree for new buildings, not to mention that the smaller ecological factor LCA calculation would have been taken into account officially. Discontinuing the support for the data transmission gate BS-PRO – Product Model Based Information Management of Building Services Implementation Process stopped the development of their ecological calculator software.

6.4 Official regulations regarding carbon footprint

Finland has a roadmap for building regulations, and material efficiency will be included in the near future. The designers may be required to reach a certain carbon footprint level per m^2 in building. How will that be assessed?

As long as there is no decree, most of the professionals will do only what they are paid for which is to design the building, not to create additional calculations. Actually there is nothing wrong with that, as cost-effectiveness is the key in enterprise management. At the moment there are no official requirements for carbon footprint nor for LCA calculation of buildings. *The National Building Code, part D3, Energy management in buildings* is the first decree regarding sustainable design in Finland. It includes some examples about how the design should be done so that the right aspects can be shown clearly. There is also a new standard over the ecological building materials under preparation. For that, more guides will be needed.

Changes along the new requirements may arise fear in some architects. They are skeptical towards new regulations and the future changes seemed to worry some architects already (Anon., 2010). The design technology has taken quite large steps forward during the last years, but some of the designers still stick to the old 2D drawing technology. Their drawing process has fulfilled the need for communicating the building design as long as any additional requirements are set. Based on 2D drawings, making any calculations requires a lot of work. Not that those using already newer versions would exploit all possibilities of their tools. When a designer has learned a way to carry out the given work in an efficient way, any changes to the workflow have to be considered as extra work. This extra work should be billed from the customer and the customer will probably not pay unless it is absolutely necessary.

The Finnish architectural society does not yet have a very strong convention of co-operating with other instances. The idea of having to interact with external experts might sound laborious and expensive, as most of the architects do not produce the energy calculations by themselves. Also the simplifications regarding the ecological calculations are criticized.

6.5 Current databases

LCA data of building products is something that will have to be discussed in the future. LCA information is very dependent on the primary sources of the energy and conversion efficiency of the materials' production processes. For example if energy source is changed from fossil to renewable, environmental impact drastically changes. The consensus over and accuracy of calculation data is the key for universally accepted and exploitable calculation results.

There are several databases commonly used in LCA calculation. They are comprehensive, but they do not fit very well to Finnish construction sites. The geological distances are longer, the ratio between domestic and imported goods is different and so on. Finland differs in many ways from Central Europe and therefore we should have own databases including values matching local facts. Transportation and manufacturing energy sources differs from those in other parts of Europe. Used materials are not exactly the same as in Europe. The national building code in Finland should update the data listed so, that the information for carbon footprint calculation would be included.

As Lylykangas mentioned in the interview, the local databases over the building materials should be created and updated. The new EPDs will help with this, but connecting the information into calculation software is another thing. Valtonen also reminded, that databases are a broad estimation of the reality, and so is the calculation as well. Also, in every country there should be a local database so that the local production methods could be taken into account. And for imported materials, at least more accurate transportation carbon footprint information can be given.

At the moment the environmental data is not available with reasonable effort, which does not help with early design phase calculations. The new EPD's according the standard EN15804 hopefully speed up the material information supply.

6.6 Problems in the design phase

In Finland there is now a growing demand for tools to create the required calculations. At the moment there are no simple tools for the building designers to help them with their work, when it comes to ecological aspects. The official requirements are not yet ready regarding LCA of carbon footprint calculation, so this has been passed. Nonexistence of official requirements explains the lack of guides as well. Still some tools should be prepared so that when the new decrees come into effect, the designers have the tools at hand. Even if the designers would be interested in the ecological aspects, the constructors are not willing to pay extra for that.

Another aspect is the design culture in Finland. The constructors are not the ones interested in the ecological calculations, the owners are. but the owners do not often have all knowledge to conduct the hands on work. Traditionally the architects co-operate with construction designers at some level, but the contact is not very strong. The artistic architectural convention might have affected into the level of co-operation. Good thing is that during the latest years the universities have started to run cross-scientific courses blending architects, construction engineers and material specialists. Maybe this will help the new generation to adopt more organic design team methods and it will be easier for them to lean on another specialist's and consultants' help.

The architects are specialists in building design but it cannot be expected that they would be experts in every sector. Exact ecologic calculations require wide know-how about the used methods and information sources. Definitely a practiced architect knows a lot about construction details and strength calculation, as well as conducting the ecological calculation. Still many architects do not have the possibility or interest to study this area. Especially if that is not of interest of the architect, using external specialists for ecological evaluations is a good idea. Valtonen thinks, the designers should get mentally ready for the new regulations.

As the designers amore often create a full BIM model, it would be convenient to use that as the base for the energy and carbon footprint calculation. According Lylykangas (Lylykangas, 2012) ecological calculations and costing could base for the same model. The costing is done anyway, so the same information could be used to ecological calculations as well. This could forestall shortcuts in the ecological modeling as well. Apart from ecological calculations, also construction technology might be something beyond many architects' knowledge. For example, a pure architectural model does not include all necessary beams and other construction details. Still, for the quantity calculation, it has quite big difference how much information there is in the model, and how detailed the model is as a whole. This is one reason why environmental consultants redraw the models. In different phases it is natural, that the models have various levels of accuracy. There is a lot of work to be done to define the sufficient information levels for every design stage. Also the calculation methods and multipliers for every phase should be created. Carbon footprint information could be included into the RT Building Information File as well. The current cards are getting old after the last eco boom and they need to be updated anyway. At the same time the sample layout could include ecological information as well.

7 Conclusions and recommendations

The goal of this study was to report the current situation of embodied carbon footprint calculation of buildings and to specify the problems in BIM based carbon footprint calculation. One possible result could have been design instructions for architects so that they can produce a correct building model for calculation use.

This study was conducted within design specialists and calculation experts. The semi-structured interviews among experts gave a lot of information even though the sampling was quite restricted.

7.1 Found problems

None of the calculation softwares mentioned in this study was able to fulfill the set requirements, which were to import information directly from the design software and calculate the embodied carbon footprint of the building. There is not any calculation tool that could have been used to conduct the embodied carbon footprint calculation, or even a simple LCA calculation, in the early design phase. All usable software was expert level specialist tools. The results from the more advanced LCA calculation softwares are not directly comparable. One common data transfer format should be used by all programs in the same style as CAD softwares already can exchange 3D information between each other.

It is difficult to create a good database that could be used in every case. Some databases do exist, but an official decisions regarding carbon footprint or LCA calculation should be taken to direct the database creation.Connecting the databases with the softwares should be easier. At the moment many softwares use only the database included into the package. In some cases it is not up to date and even if it would be, it actually does not give accurate values for all regions.

As the study progressed it was revealed that actually there was no clear instructions to create a simple, early phase calculations. Currently the carbon footprint, or even LCA methodologies are too complicated to be widely accessible. Only the calculation experts know how to apply the complicated standards correctly, and how to use some of the few, large and tortuous calculation softwares. There are several standards to define the process, but all of them allow exceptions during the calculation process. Reading the evaluation description can show unexpected choices taken during the evaluation.

At the moment there is no official requirement for the carbon footprint calculation, so it is not surprising that no extra work is done. There is no convention on the building sector to ask for carbon footprint calculation in normal projects. Onerous calculation work is done only when explicitly needed. Architectural offices did not want to participate the interviews adverting to rush at work. It shows that environmental actions (and studies regarding them) are not prioritized at the moment. There is no need or time to think about them.

The fact that the calculations are done rarely leads unavoidably into a situation where the work flow from the designers' plans into ready calculations is not clear and smooth. The information path should build up and conducting carbon footprint calculation at any level would probably get faster.

Architects have quite artist driven design tradition here in Finland. The mentality is to create beautiful design, and the engineers do the math. The problem is that the changes made in the very beginning are always cheaper, so the architects should treat the calculations with a bit more benevolence. The environmental thinking could be part of the proficiency of an architect. They do not need to calculate the real numbers, but usage of any design directive calculation software could help to avoid the biggest carbon footprints.

7.2 Proposals

Exact carbon footprint calculation tools should be developed into that direction, that they can intake information directly from any IFC compatible BIM software. In practice this means that the calculation softwares should become IFC compatible. Despite of this, CAD programs should include some kind of carbon footprint calculators that would guide the designer in the early phase of the project. The differences between the calculation results based on architectural and more detailed construction model should be studied as well. This information could be used to create multipliers between the calculation results between various project phases. The new IFC4 definition includes environmental parameters. They should be examined carefully and the instruction for the architectural design should be upgraded to include all of the important aspects regarding this. It is part of the professional ability of the architect to be able to create modern models that can be exploit by the other members of the design team. The architect do not need to know everything, but they should not look down on other parties' needs either. Good instructions for every BIM design tools and clear guides what to take into account are absolutely necessary.

Changing the ambience more favorable for the ecological calculations is a slow process. Implementing official carbon footprint requirements into the building design would generate instant demand for solutions to calculate the carbon footprint. That would lead to production of common design and calculation instructions, and they would be taken more actively into use. The atmosphere should be changed so that designing ecologically sustainable buildings is the natural way to choose in every project. It will take time, and it requires working tools and operations models.

Architectural competitions could take more notice on ecological aspects of the entries. It would encourage the designers to think about the ecological aspects, and to find easy ways to get the light calculations done.

8 Summary

The aim of this study was find out, how the building information model (BIM) data is utilized in embodied carbon footprint calculation. No directly compatible calculation tool was found. The results of this study include a list over various carbon footprint calculation tools.

One example of this would have been, how detailed and accurate the information is, or should be, in every design phase. In short, how to create a usable BIM model while modeling the building as an architect. The original aim was distant compared to the current situation. Therefore the study was limited to sweep the field of building design and calculation methods and tools at the moment to give a picture about the development needs at the moment.

The goal of this study was to report the current situation of the carbon footprint calculation in the early stage of the building design. The environmental calculations have been within the picture since early seventies. Building sector is one of the largest energy consumers of the society and therefore even smaller parts of it have extensive effects into ecologic footprint of human being. Methods to evaluate the emissions and environmental effects has been created. In addition to this the BIM programs have advanced in breakneck speed. Reflecting to these changes it is difficult to believe that there still is actually not functional workflow to make any design steering calculations. All found embodied carbon footprint calculation softwares, which practically meant LCA calculation tools, were specialist level programs for heavy calculation.

To help the building designers in their work, the currently available calculation softwares were presented together with the most common architectural BIM software. However, the framing of this study presumed compatibility with IFC and none of the calculation softwares fulfilled this requirement. The building design softwares could export material quantity information for the calculation, but the calculation softwares could not import the data without error prone, manual interference.

The carbon footprint evaluation softwares should be directly compatible wish the building design softwares. Using APIs or even standardized table format could be useful methods. The most advantage of the carbon footprint calculation could be received, if it could be implemented in a very early phase of the design. The calculation result would be more accurate if based on the late version of the building model, but then it might be late to make large changes into the model. So it would be important to develop calculation tools that could be integrated with the building design programs used by the architects. The tools should have, for example, inbuilt estimations for multipliers, as a simple model does not include all building details that in their behalf do affect the carbon footprint.

Building designers do not feel that they could be compelled to do things beyond their competence. Intelligibly their core competence is to design buildings. Some architects improve their ecologic design skills voluntary. To get several designers interested in ecologic evaluations the tools should be easy to use. At the moment the calculation is conducted by specialists with heavy duty calculation softwares. It is expensive and therefore rarely done.

There are several standards that help to define the carbon footprint calculation. They are clear, but implementing them is not directly straight forward work to do. Even though it is clearly described how to calculate the carbon footprint, there still is many decisions to take for the calculator and depending on the decision, the result may differ. And therefore the results are not directly comparable.

Connecting databases into building design software would help to estimate the carbon footprint already in the design phase. It would be faster and reduce the variation within calculations. Modern BIM software have advanced quantity calculation capabilities that could be easily utilized. There are several large databases about building materials, but they should be refined in many ways. In building industry the product information and carbon footprint values are partly very area specific, the same values cannot be used everywhere. Also database information in the early calculations does not need to be as detailed as in the final report. These differences should be examined and databases should be improved based on the results.

There is still some way to go before carbon footprint calculation is de facto in building design. There are not yet accurate tools that would be suitable in the early design stage, and the EPDs of the used products, which would facilitate more advanced LCA applications, are not yet available. Official requirements could speed up the implementation of this type of evaluations. At the moment ecological values are overridden by money very often. Any optional evaluations are rarely done. The energy efficiency of the building does affect the environment more than what the carbon footprint of the building does, there already exist official requirements for that. Maybe carbon footprint calculation is the next official step towards a greener future.

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A Appendix

A.1 English interview question frame

Introduction into the interview

This interview is part of my master's thesis at Aalto university at Forest Products Technology department. My master's thesis is part of the €CO2 – Wood in Carbon Efficient Construction EU-project (http://www.eco2wood.com/). The project covers five European countries and some one hundred experts.

In my part I study the BIM compatible calculation methods of the embodied carbon footprint of the construction materials. It doesn't mean the same as the carbon footprint or energy usage of the building. It refers to the carbon footprint bound to the materials during the production of the materials. In other words it's part of the LCA calculation of the building.

Object of the interview

Through this interview I wish to clarify current embodied carbon footprint (FC) calculation methods and customs. The main interest is on BIM compatible calculation software, how they work and how they should be developed. Also I'd like to hear how the calculations are done now, or are they performed at all. What should be done to make calculations easier?

It's good to reserve at least one hour for the interview.

Usage of the interview material

The information gathered will be used in my master's thesis. If possible and if the interviewee gives permission, I'll gladly record the interviews. The recordings will not be used to other purposes and they won't be stored after the final work is done.

This document work as a frame to the questions, but the interview doesn't need to follow it slavishly.

Questions

Basic information

Information is gathered for reference.

- Name, status and expertise of the interviewee.

Background information

Clearance of the current situation. Because the object of the interview is to report current customs about embodied carbon footprint calculation, the questions are limited correspondingly.

Used software

- What CAD programs do you use at work?
  - How often and intensively do you use these CAD programs?
  - Which versions do you use?
- What other programs do you use at work?
  - Which of the FC related softwares are the most important?
  - Are they basic versions of the software, or special editions modified for planning and/or calculation?

Projects of the designer

- What kind of design or calculation projects do you handle at work?
- Do you take part into building design?
- How much and what type of source information do you get in the beginning of the design or calculation process?
  - Do you know from the very beginning, what all calculations are needed and will be performed?
- What documents do you forward from the projects? (Something special?)

Advanced questions

In this section I'll try to get further development ideas regarding CF calculations and list the shortcomings.

Ecological calculation about the buildings

- What kind of environmental calculations from the building plans are done as a whole?
  - What are the calculation results used for?

  - Do you calculate something apart from what the authority requires?
  - In different design phases, are there different calculations or does the information sharpen along the process?

- In which stage is the CF calculation done or started?

  - For what purpose are the calculation performed?
  - Do you calculate something apart from what the authority requires?
  - In different design phases, are there different calculations or does the information sharpen along the process?

- How is the CF calculation divided during the different building design phases?
- How is the CF calculation divided between the design stuff?
- What software is used for the CF calculation? Or is it ordered from elsewhere?
- *(Additional information that might be useful.)*

Information used for CF calculation

- What type of information is used when starting to calculate FC?

  - Where does the source information come from?
  - Is this enough?

- What kind of databases are used for the calculation?

  - Are the databases comprehensive and easy to access?

Problems and development needs

- What kind of problems have you met while performing CF calculations?
- How could the technology help the designer to take the CF calculation into account? For example a software, additional feature...
- Does the information flow enough?

  - Is important information often missing?
  - Does the source information change often during the design process?
  - Is it possible and easy to send information further?

- What tools would you take to help the process?

Thoughts

- What do you think is the role of the designer, if we are talking about the environmental impact of the buildings?
  - What do you think about the current official requirements?
  - In which direction they should or should not be directed?
- How do you consider sustainable design in you own design?

Summary

Is there now something in your mind that I didn't understand to ask, related into the subject?

Finale

This was everything, thank you. Your answers will help me a lot in my master's thesis!

- Would you like to receive information about the ready work and hear about the results of the €CO2 project?

A.2 Suomenkielinen haastattelurunko

Johdanto haastatteluun

Tämä haastattelu on osa diplomityötäni, jota teen Aalto yliopistolla, nykyisellä biotuotetekniikan osastolla (entinen puunjalostustekniikka). Diplomityöni on osa €CO2-nimistä puurakentamisen EU-hanketta (http://www.eco2wood.com/). Projetissa on mukana osapuolia niin yliopistoista kuin yrityksistäkin Suomesta, Ruotsista, Saksasta, Itävallasta ja Italiasta.

Omassa diplomityössäni keskityn rakenteisiin sitoutuneen hiilidioksidin (embodied carbon footprint) laskentaan. Kyse ei siis ole rakennuksen kuluttaman energian muodostamasta hiilidioksidijalanjäljestä vaan siitä hiilidioksidista, mikä rakennukseen sitoutuu käytettyjen materiaalien ja valmistusmenetelmien takia jo rakennusvaiheessa. Toisin sanoen kyse on pienestä osasta rakennuksen LCA-laskelmaa.

Tällä hetkellä viranomaismääräykset eivät Suomessa edellytä tällaisia laskelmia, mutta jossain yhteyksissä laskelmia kuitenkin tehdään.

Haastattelun tarkoitus

Tällä haastattelulla pyrin selvittämään rakenteisiin sitoutuneen hiilidioksidin tämänhetkisiä laskentatapoja ja laskennan yleisyyttä. Mielenkiinnon kohteena on tämänhetkisten ohjelmistojen toiminta, niiden edut ja puutteet sekä mahdolliset muut huomionarvoiset seikat. Lisäksi toivoisin saavani kehitysehdotuksia nykyisiin toimintatapoihin.

Haastatteluun olisi hyvä varata aikaa noin tunnin verran.

Materiaalin käyttö

Haastattelun avulla saatuja tietoja käytetään diplomityön taustamateriaalina. Äänitän haastattelut mielelläni, jos haastateltava antaa siihen luvan. Äänitteitä ei käytetä muihin tarkoituksiin eikä niitä ole tarkoitus säilyttää diplomityön valmistumisen jälkeen. Tämä dokumentti on koottu haastattelijan kysymysrungoksi, mutta haastattelun ei ole pakko seurata suunnitelmaa.

Kysymykset

Perustiedot

Tiedot mm. viitteitä varten.

- Haastateltavan nimi, työpaikka ja työnkuva.

Taustatietoja

Nykytilanteen kartoitus. Koska haastattelun tarkoituksena on selvittää lähinnä rakenteisiin sitoutuneen hiilidioksikin aiheuttaman hiilijalanjäljen (HJJ) määrittelyä tämän hetken työkalujen avulla, kysymykset on rajattu sen mukaisesti.

Käytetyt ohjelmat

- Mitä CAD-ohjelmia käytät työssäsi?
  - Kuinka usein ja intensiivisesti käytät ohjelmia?
  - Mikä versioita käytät?
- Mitä muita ohjelmia käytät työssäsi?
  - Mitkä ovat tärkeimpiä ohjelmia liittyen HJJ:n laskemiseen?
  - Ovatko kyseessä perusversiot, vai suunnittelua ja/tai laskentaa varten modifioidut versiot?

Suunnittelijan projektit

- Millaisia suunnittelu- tai laskentaprojekteja käsittelet työssäsi?
- Osallistutko rakennusten arkkitehtuurisuunnitteluun?
- Millaisilla lähtötiedoilla suunnittelu yleensä aloitetaan?
  - Tiedetäänkö alusta asti, millaisia laskelmia mallista pitää pystyä tekemään?
- Mitä dokumentteja toimitatte eteenpäin? (jotain erityisiä?)

Syventävät kysymykset

Tässä osassa tarkastellaan syvällisemmin HJJ:n laskentaa ja käytettyjä menetelmiä sekä selvitetään puutteita ja kehitystoiveita.

Rakennuksen ekologisuutta koskevat laskelmat

- Millaisia ympäristölaskelmia suunnitelmista ylipäätään tehdään?
  - Mihin tarkoitukseen laskelmat tehdään?
  - Lasketaanko viranomaisvaatimusten lisäksi jotain muuta?

  - Tehdäänkö projektin eri vaiheissa useampia laskelmia eri lähtötiedoin tai eri tarkkuuksilla?

- Missä vaiheessa prosessia HJJ:n laskeminen tai arvioiminen aloitetaan?
  - Mihin tarkoitukseen laskelmat tehdään?
  - Lasketaanko viranomaisvaatimusten lisäksi jotain muuta?
  - Tehdäänkö projektin eri vaiheissa useampia laskelmia eri lähtötiedoin tai eri tarkkuuksilla?
- Miten työskentely (HJJ:n laskentaan liittyvä) on jaettu projektin aikana?
- Miten työskentely (HJJ:n laskentaan liittyvä) on jaettu tiimin kesken?
- Millä ohjelmilla laskelmia tehdään, tai miten ne teetetään?
- *(Tarkempia tietoja.)*

HJJ:n laskennassa käytetyt tiedot

- Millaisilla lähtötiedoilla HJJ:eä lähdetään laskemaan?
  - Mistä lähtötiedot tulevat?
  - Onko lähtötietoja riittävästi saatavilla?
- Millaisia tietokantoja laskennassa käytetään?
  - Ovatko tietokannat kattavia ja helposti saatavilla?

Ongelmat ja kehitystoiveet

- Millaisia ongelmia olet kohdannut hiilijalanjälkiä laskettaessa?
- Miten tekniikka (esimerkiksi ohjelma) voisi auttaa suunnittelijaa huomioimaan HJJ:n laskenta?
- Liikkuuko tieto riittävästi?
  - Jääkö usein tärkeitä tietoja saamatta?
  - Muuttuuko (lähtö)tieto projektin aikana?
  - Saako tietoa vietyä eteenpäin?
- Millaisia työkaluja toivoisit avuksi?

Ajatuksia

- Mikä mielestäsi on suunnittelijan rooli, kun puhutaan rakennusten ympäristövaikutuksista?
  - Mitä mieltä olet tämänhetkisistä viranomaisvaatimuksista?
  - Mihin suuntaan niitä pitäisi tai ei pitäisi kehittää?
- Miten itse otat ympäristön huomioon suunnitelmissasi?

Yhteenveto

Tuleeko mieleesi jokin sellainen asia, joka liittyy haastattelun aiheeseen, mutta jota en osannut kysya?

Päätös

Tässä olikin kaikki. Kiitos, vastauksesi olivat minulle iso apu diplomityön kannalta!

- Haluatko saada tiedon valmiista diplomityöstä ja kuulla EU-projektin tuloksista?